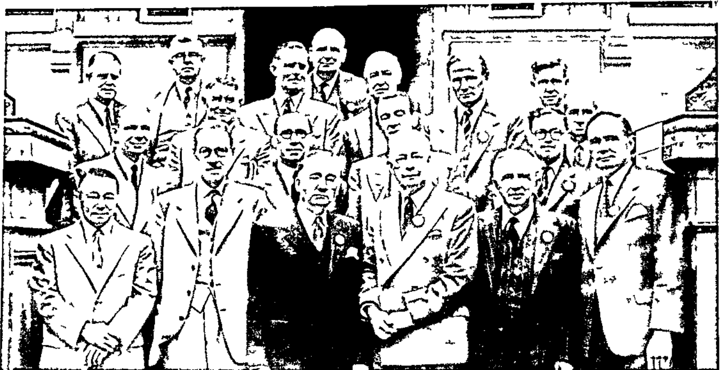
PULMONARY CIRCULATION
AND
RESPIRATORY FUNCTION

A
SYMPOSIUM
HELD AT
QUEEN'S COLLEGE



DUNDEE

UNIVERSITY OF ST ANDREWS
1956



Front r w—Prof o A A L bow P fessor J B Dugu d P fe s G H Bell Dr I d Burgh Daly P fe so D R Dow Pr f so R B H nter M ddle ow—Prof sor W Melville Arnott Profe so J McM h el S r Ru sell Brock Dr K W Donald D D V Bat P ofe sor Ian G W H ll Ba k row—P ofessor A C L ndrum P ofesso J Gough Professor D M Do gl D Coope Professor P R All son Dr C M Flet h r and Dr G S Dawes

INTRODUCTION

When it became known that Dr Averill Liebow Professor of Pathology of Yale University was to be the Praelector in Pathology at the University of St Andrews for 1955 it was felt to be a unique opportunity to bring together those in Britain who had a special interest in the lungs The Faculty of Medicine conscious of the sad walls that bound the specialties decided to call together for a symposium workers within the pulmonary field be they physiologists or physicians surgeons or pathologists The Court of the University of St Andrews agreed to support the scheme and so there met in September 1955 at Queen's College Dundee the group whose names are listed elsewhere

As a jejune youth said recently By good luck Providence was on our side and it was generally agreed that the stimulating air of the Firth of Tay produced a genial indeed a happy and productive conference Many have already expressed the gratitude due to those who offered fresh views fertile ideas and friendly discussion and to these we would add the Thomson Press of Dundee who have produced this volume of proceedings

The Editors

Pulmonary Circulation In Health And Disease

15th SEPTEMBER

Respiratory Function

16th SEPTEMBER

Pulmonary Vasomotor Nerve Activity And Its Possible Functional Significance

I DE BURGH DALY (Institute of Animal Physiology Babraham Cambridge)

Whether pulmonary vascular resistance is normally modified by extrinsic vasomotor nerves is still a controversial issue (1 2) In discussing this problem two kinds of evidence will be considered here —

(a) The results of animal experiments in which pulmonary ventilation and circulation are controlled artificially and

(b) P V R (pulmonary vascular resistance) measurements obtained on human subjects

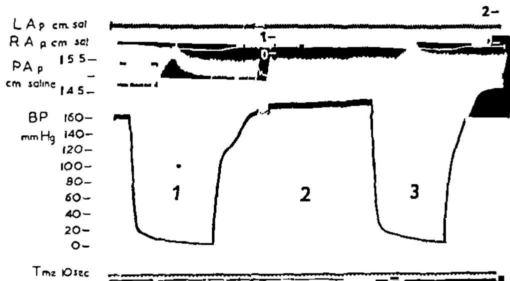
Experiments on perfused lungs of animals (3) chiefly dogs were originally designed to meet the difficulty that large passive changes in pulmonary flow pressure and resistance may obscure or vitiate the demonstration of active vasomotor nerve responses Passive changes in resistance can occur secondarily to alterations in lung blood flow or as the result of broncho constriction or any change in ventilation that alters the intrapulmonary pressure Because of the communications through the bronchial system (4) of vessels between the systemic and pulmonary circuits other errors may arise for the effects of a change in resistance of the bron chial arteries and their communicating vessels due to bronchial vasomotor activity (5) or of a change in systemic pressure (6) can be trans mitted to the lesser circuit

To eliminate such effects innervated isolated lung preparations (7) were perfused at constant volume inflow or at a constant head of pressure with free outflow of blood from the left auricle Bronchomotor effects which are particularly suspect (8 9) were regarded as absent during nerve stimulation tests if the tidal air or ventila tion overflow remained constant under con trolled negative or positive pressure ventilation respectively these methods record both changes in lung viscance and elastance but do not distinguish between them In other experiments on whole animals with a widely opened thorax the systemic vessels were also perfused at constant blood volume inflow (10) To demonstrate the existence of pulmonary vasomotor nerves both the sympathetic and parasympathetic trunks supply ing the lungs have been stimulated Pulmonary vascular responses to such stimulation are regarded as proven only if they can be demon strated at zero systemic blood pressure and in the absence of any bronchomotor response (Fig 1)

To eliminate bronchoconstriction (broncho dilation rarely occurred) it is usually necessary to atropinize the animal This may account for the fact that the predominant motor response is vasoconstrictor since the vasodilator responses which have been obtained from time to time are atropine sensitive

The net result of these experiments is to show that both vasoconstrictor and vasodilator fibres are present in the autonomic nerve supply of the lungs and from pharmacological evidence it appears that most of the vasoconstrictor fibres are sympathetic in origin with cell stations in the stellate and middle cervical ganglia and with post ganglionic neurones which are adrenergic So far as they go these experiments seem con clusive But in order to effect all the controls necessary to demonstrate unequivocally active pulmonary vasomotor responses the conditions of the experiment become highly artificial and may possibly lead to a modification of normal responses This is suggested by the observation that an initial sympathetic nerve stimulus or adrenaline injection sometimes reduces the P V P whereas subsequent similar procedures raise the P V R Is it possible that perfusion leads to sensitisation of the vasoconstrictor or to paralysis of the vasodilator neuromuscular apparatus? The P V R of perfused lungs is much greater than normal which may be predominantly due to constriction of vessels other than those responsive to nerve stimulation with the result that the responses are greater than normal The results may therefore represent the physiological potentiality of the lungs rather than the normal working mechanism

The demonstration of an independent control of the lung vessels in human subjects requires that in some way passive effects as outlined above be eliminated Since a change in cardiac output per se alters the P V R there is no justification for attributing recorded changes in P V R (Δ p/flow) to a vasomotor nerve control unless it can be unequivocally established that there are no accompanying changes in cardiac output and efficiency (such as to alter the left auricle pressure) An increased bronchial circu lation development in pathological lungs so beautifully demonstrated in detail by Doctor



F gu 1—S planat on page 4

F gu e 2

ACTIVE (——) AND PASSIVE (— —)

EFFECTS ON THE PULMONARY VASCULAR BED

Respiratory centre activity

Inspired gases

Hormone release

Vagal or thoracic sympathetic nerve activity

Alveolar gases → Blood

Systemic vasomotor

Cardiomotor

Bronchial vasomotor

Bronchomotor

Pulmonary vasomotor

Systemic blood vessels

B P changes

Bronchial circulation blood vessels

Pulmonary Vascular Bed Response

Elbow would be expected to enhance passive effects due to blood transfer Events leading to active and passive effects on the pulmonary vascular bed are shown in Fig 2

The site of action of pulmonary vaso constrictor fibres is a matter for speculation especially in relation to their effect on functional blood redistribution They may cause an inter mittent and asynchronou constriction of pulmonary arterioles supplying individual terri torial units and thus determine the number and localisation of perfused units Intermittent activity of alveolar capillaries (11) and of lobar bronchi has been described (12) Vasomotor nerve activity may cause venule constriction which if transient would serve as a normal mechanism for passively dilating alveolar capillaries If as is suspected some of the capillaries are constricted in lung perfusion experiments our observations may be equally well explained on the hypothesis that sympathetic nerve stimulation closes down pulmonary artery pulmonary vein communicating channels (4) or the larger alveolar capillaries thus causing a diminution in total blood flow or a shuntin of blood through a higher vascular resistance bed of inactive capillaries or of partially constricted capillaries If this were the mechanism under normal physiological conditions sympathetic activity would increase the alveolar capillary blood flow

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Figure 1

Bit I 18 0 kg Inn rv ited isolat d p rfused left lung I rfu on of bronchial circul t on n d essel upplying the tra pulmon ry n rves perfu ion of pulm n ry circul t on at a const nt h ad of pressure Positi p es ure ntil tion V ntil t on o rfl m ur l by m tl od of Konzett and Rossl r (13)
1—Stimu at n of entral branch of left annulus of Vi u en at 5 volts/10 m ec/ 0 per sec The P V R incre sed by 46 Tid l a r=59 ml
In pir tory pres ure reduced in steps from 14 5 to 1 5 cm H_2O th n incr sed to 13 5 E pirators pres e throughout 5 m H_2O The P V R m in unch ge l
2 *Stimulation of l ft annulu branch 5/10/ 0* The P V R incre sed by 35 T dal r=53ml

L A =l ft u cl R A =right ur cl P A = p lmon ry rtery

The Pulmonary Circulation In Health And Disease

K W DONALD (Department of Medicine University of Birmingham)

The lesser circulation is a miracle of structural simplicity and a nightmare to the student of integrated function The whole cardiac output which may reach levels of 30 l /min is pumped through the lung by the relatively weak right ventricle where it is intimately divided and effectively exposed to the lung atmosphere The outflow pressure must be maintained at low levels as a relatively slight increase of venous and capillary pressure will cause a great outpouring of circulatory fluid into the lung alveoli

The low impedance of the pulmonary circu lation is now well known Hickam and Cargill and Riley et al in cardiac catheterisation studies on normal subjects described how very con siderable increases of cardiac output on exercise

caused little change in the pulmonary arterial pressure They considered that this decrease of pulmonary vascular resistance during exercise could only be due to the widening of the vascular channels or to the opening of new channels Cournand combined his studies of pulmonary arterial pressures after pneumonectomy with those of Riley and concluded that there was no significant increase of pulmonary arterial pressure until the rate of blood flow through the lungs exceeded 10 l/min/m²

Dexter and ourselves have not been able to confirm this in subsequent studies Our observations in normal subjects suggested that the pulmonary vascular resistance remains fairly constant and that there is a proportionate increase of pulmonary arterial pressure as the flow rises These findings are more in accord with the older concept that on exercise the pulmonary circulation transmits the blood pumped by the right ventricle almost passively

The measurement of pressures in the left auricle and pulmonary vein in the intact human presents great technical difficulties The passage of the catheter through an atrial septal defect or an unclosed foramen ovale gives figures in the region of 5 8 mm Hg but the possibility of abnormal hæmodynamics under these conditions must be borne in mind The pulmonary capillary pressure is even more difficult to determine Hellems and his colleagues impacted the catheter in one of the lesser radicles of the pulmonary artery and measured the pressure cautious in their conclusions they felt that as the blood withdrawn was fully oxygenated there was probably full communication between the impacted catheter and the capillary bed This and the fact that the pressures were a few mm higher than in the left atrium suggested that this was a reasonable approximation to pulmonary capillary pressure However it is probable that the blood flow through the whole of the lung segment concerned is brought to a standstill by this procedure and that there is little if any collateral anastomosis with other segments Under these conditions the vascular bed is now being employed as an imperfect and unusual extension to the catheter connecting it with the pulmonary veins The static circulation of this segment can thus be used to aspirate pulmonary venous blood or to record a crude transpulmonary venous pressure

Allison s remarkable technique of needling the left auricle from the air passages has shown very similar pressure levels and variation as recorded directly and through the impacted catheter (Epps and Adler) Yet these studies were in patients with considerably raised pressures and animal experiments still cast doubt on complete concordance when the pressures are normal

Experiments with animal and perfused human lungs have shown the passage of small spheres far larger than could pass any capillary bed There is still considerable debate about the significance of such experiments but the general consensus of opinion is that although there are probably arterio venous shunts they are more potential than functional in the healthy normal subject Indeed significant short circuiting of the alveolar capillaries with their negligible resistance would appear both unlikely and against the interests of the organism

The occurrence of precapillary anastomoses between bronchial arteries and the pulmonary circulation has also been studied a great deal recently Animal experiments again suggest that although these may exist in the normal animal or human subject they are again more potential than functional In many diseases this anastomosis can become very considerable

Finally we come to the great problem of vasometricity of the pulmonary vascular bed On the whole it remains unsolved Changes of pulmonary resistance in response to various stimuli such as anoxia adrenaline hypotensive drugs etc have been shown in many animal and some human experiments Yet these results are so frequently different with varying techniques and circumstances and between different species of animals that one begins to wonder whether they are an important significant factor in circulatory function in health Admittedly nerve endings and receptor organs have been shown in the pulmonary artery and veins and nervous impulses varying with pressure in these vessels have been recorded Joseph Barcroft felt that their very presence must have some significance yet even his amazing intellect could see no further I would make a most tentative suggestion that although there is undoubtedly some vasometricity of the pulmonary vessels this may be an example of vestigial function which is no longer of importance Extreme and even differential changes in blood flow of the gill arches would appear to be a reasonable necessity in the early stages of evolution but marked changes in the resistance of the pulmonary circulation in response to various stimuli may be no longer necessary and even undesirable in healthy mammalian life That almost vestigial structure the coccygeus which still contributes as a very minor and almost unwanted attendant in tidy defæcation used to

wag the tail. Is it possible that vestigial vaso-motricity of the pulmonary bed has wagged the dog and given us this *discouraging array of* contradictory protocols.

Pulmonary Circulation in Disease

The pulmonary circulation is as variable in its response to disease as it is to experimental procedures. The outstanding problem is the development of increased resistance to flow and of pulmonary hypertension in various diseases.

In mitral stenosis there is a considerable increase in pressure behind the mitral valve and at first the pressure gradient in the lung vessels behind the obstruction remain the same, all pressures rising by roughly the same amount. Many such patients are still capable of almost normal activity and are in constant danger of acute pulmonary oedema. This is presumed to be due to the capability of these patients to *increase their cardiac output but only at the price* of high pressures behind the mitral valve. A further possible contribution may be an *increase of rapidly circulating blood volume* owing to the diversion of blood from the splanchnic and resting areas. In the presence of *a normal resting cardiac output there is* little vasoconstriction in these areas at rest and therefore a considerable volume of blood can be diverted from them on exercise.

In time varying degrees of further pulmonary hypertension develop in most patients with mitral stenosis, the considerably increased gradient across the lung being presumably due to increased pulmonary arteriolar resistance. The degree of increase and the rate at which this occurs is at present quite unpredictable. The pulmonary artery pressure may rise to very great heights in a young child in a few years whereas another patient who has tight mitral stenosis and considerably raised transpulmonary pressures may not develop marked pulmonary arteriolar resistance for many years, *if at all*.

The fact that patients with an increased pulmonary resistance, although usually more disabled in everyday life, rarely develop fulminating pulmonary oedema is held by some to suggest that this increased arteriolar resistance is *protecting the capillaries from sudden and* dangerous rises in pressure. Yet the only possible result of this increased precapillary impedance, *if the right ventricle does not fail, is far greater* work for that ventricle and higher pressures in the pulmonary artery to maintain the blood *flow*. We do not hear of systemic hypertension having any direct hæmodynamic effect on the capillary bed even when there is associated congestive failure. The systemic and pulmonary capillary pressures are influenced by the venous *pressure* which is in turn influenced by atrial pressures. If the mitral valve impedance to outflow from the lungs remains constant or *increases there would appear to be only* one favourable circumstance in which the back pressure in the lung vessels could be reduced and that is with a *reduction in blood flow. It is well* known that the cardiac output is usually considerably decreased in these patients and that it is *often unchanged on exercise. This is almost* certainly due to the increased mitral valve obstruction. The stroke volume at rest is small and any increase in pulse rate, unlike conditions in the normal subject, is only at the cost of even more impaired ventricular filling with reduction in stroke volume and little or no resultant increase in total flow. Thus these patients are no longer capable of producing sudden increases of flow and a surging of blood against the mitral valve. It may be suggested that the considerably increased pulmonary arteriolar resistance will of itself cause a reduction of right ventricular output and thus guard the impeded lung circulation from further rise of venous and capillary pressure. Yet this is not the case either with the *right or left ventricle working against increased* resistance until after failure supervenes. Another possible cause of relief from severe rises in *transpulmonary pressures could be a favourable* alteration in the pressure volume characteristics of the left atrium and pulmonary veins. It is *fortunate* but nevertheless fortuitous that these more disabled patients are less prone to acute pulmonary oedema. The word protection is in any case undesirable as it is difficult to believe that a species evolves purposeful protective mechanisms against such severe chronic crippling diseases in an unfortunate minority.

Returning to the enigma of pulmonary hypertension in disease we still do not know why some cases with increased pulmonary flow such as occurs in patients with a patent *ductus* arteriosus or intra-auricular defect develop severe and killing pulmonary hypertension and *yet others who are in no way different* as far as we can tell do not develop increased pulmonary vascular resistance. How much this *rise in pressure* is due to morphological changes in the vessels or due to increased vaso-motor tone is not yet clear. Pressure and even histological studies after the correction of obstruction or increased flow, although of great clinical importance, will not entirely solve this problem. The genesis of hypertension in the pulmonary vascular bed remains as great a mystery as that of systemic hypertension. We have far to go.

Some Applications Of Basic Knowledge Of The Collateral Circulation Of The Lung

AVERILL A LIEBOW (Department of Pathology Yale University School of Medicine New Haven Connecticut U S A)

The establishment of a pulmonary collateral circulation provides a means for redirecting the flow of blood through the lungs that may be useful in therapy

Congenital transposition of the great vessels presents circulatory problems that are at least partly subject to surgical revision Ligature of all pulmonary veins in the dog is followed by a large collateral circulation that drains fully oxygenated blood from the operated lung into the azygos and other systemic veins and thus to the right side of the heart (1 4) The volume of blood flow through this system reaches approximately one sixth of what would be expected under similar conditions of anaesthesia had the lung been intact (4) The ready establishment of these collaterals and the considerable magnitude of the flow obtained in a relatively short interval of time (3 5 months) suggests that ligature of the pulmonary vein might be one approach to securing a left to right shunt of highly oxygenated blood that ordinarily would circulate through the left side of the heart in instances of transposition of the great vessels This shunt would aid in the refreshment of the desaturated blood that pursues a course through the right sided systemic vascular circuit in these patients One advantage of the suggested procedure is that the shunt *carries the blood* inevitably from left to right whereas the course of the blood after the creation of a *defect in the* inter atrial septum is unpredictable One possible difficulty is that the venous pressure might rise to high levels when the pulmonary veins are occluded under the circumstance of the markedly elevated pulmonary arterial pressure that usually prevails in these patients (5) A method of circumventing this problem would be to ligate both the pulmonary arterie and veins This procedure has proved feasible in the dog without infarction of the lung or abolition of its respiratory function The blood flow through such a lung supplied entirely from the aorta and draining into the *right heart only* slowly rises to levels of 300 to 500 cc (occasionally more) in three to six months time Were this procedure to be practised in transposition the ultimate effect would be simply the introduction of a lung into the systemic vascular circuit (Fig 1)

The enormous blood supply to the lung from the aorta via bronchial arteries that is induced after interruption of the pulmonary arterial inflow (7 9) may be applied as collateral blood supply to the heart by cardiopneumonopexy (10) After this procedure three types of anastomoses have been observed —1—Tran pleural Anastomoses—these may reach a diameter in excess of 1 mm and join branches of the coronary and bronchial arteries (Fig 2) 2—Retrocardiac Anastomoses—that connect enlarged branches of the left circumflex coronary artery usually the left atrial with bronchial vessels along the major bronchi or within the mediastinum 3—Inter coronary Anastomoses Studies of the hæmodynamics by means of angiography and catheterization have revealed that after approximately one year some 5% of inflow into the coronary sinus is received from the collateral vessels The direction and volume of flow are measured by introducing Evans blue dye at a point into the aorta just above the ostia of the collateral vessels and simultaneously measuring the dye concentration curves at 4 points —In the femoral arteries in the coronary sinus in the right atrium in the carotid artery (proximal to the point of introduction of the dye)

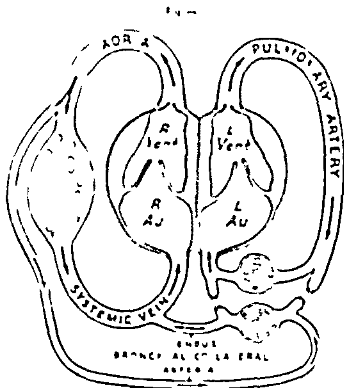
It may be suggested that simple cardiopneumonopexy without ligature of the pulmonary artery would be highly desirable in most instances of transposition of the great vessels In these individuals the pulmonary arterial pressure usually exceeds that in the systemic arteries such as the coronary arteries and the latter also contain desaturated blood

It is obvious that only the last of these various procedures is without cost in terms of pulmonary function This cost may nevertheless be worth the possible benefit to be obtained

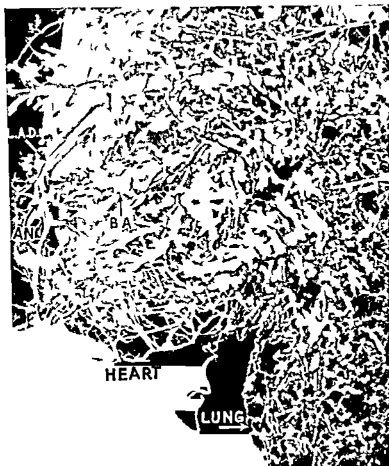
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ARTERY
R
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SYSTEMIC VEIN

F gure 2



Th g on of l ft rd opn umonope y after ligature of th pulmon ry artery perform d 10 m nths p evı u ly ı shown f om the late al pect M y l g t n pl u l n tomose on of wh h s lab ll d AN d m n tr ted to jo n the left anterior d scend ng co on ry artery (L A D) and greatly e l g d b o ch l teries On of th l tt (B A) ndic t d b y n ow in th photograph as it spirals about the bron hus A d nse n twork of bron hi l a terie c n b n n th l ng n the lowe margin of th photogr ph at the right

Observations On Control Mechanisms In The Right Ventricle In Health And Disease

SIR RUSSELL BROCK (Guy s Hospital London, S E I)

Others will no doubt deal with details of the *circulation within the lungs* I propose to present some of my observations and experiences in connection with the more central control of the pulmonary circulation as exemplified by the action of the *outflow tract of the right ventricle in* both health and disease In particular I wish to record observations and deductions made from my experience in some 250 direct operations for pulmonary stenosis

The Normal Right Ventricular Outflow

It is first necessary to consider briefly the construction of the normal right ventricular outflow tract from its funnel shape it is often called the infundibulum When examined after removal of the atria and the superficial investing *layer of circular muscle fibres it stands out as a* separate part of the right ventricle in a manner suggesting it has a separate function

The key to this lies in its development In the *fish and the amphibian heart the bulbus cordis* exists as a separate part or chamber which is not seen in the mammalian heart except during its development It then loses its identity by becoming absorbed into the musculature of the infundibulum

Keith in 1904 suggested that this separate anatomy and morphology of the infundibulum indicates a separate function from the rest of the right ventricle *He pointed out that in the gill* breathing vertebrates the bulbus receives the load of the ventricle and forces it onwards into the aorta leading to the gills and act as a mechanism *controlling the flow and the efficiency of the* valves He suggests that in man the competence of the pulmonary valves depends on the tonus and action of the infundibular muscle and quotes experiments of Gibson (1898) to support this

These experiments have been repeated and confirm the part the ventricle plays It is pointed out that the right ventricle does not contract as a whole but a progressive wave of contraction passes up the infundibulum this can be observed with the naked eye when carefully looked for but i perfectly demonstrated in a slow motion film such as that of Prinzmetal

In *addition it is likely that variations in tonus* of the outflow tract are of importance in the function of the right ventricle Variations in tonus are probably the cause of the attacks of severe cyanosis and loss of consciousness seen in Fallot s tetralogy it is otherwise difficult to account for them If the tonus of the infundibular muscle increases the pulmonary stenosis *is made worse and less blood goes to the lungs* at the same time more venous blood is shunted into the aorta As cyanosis increases and the condition deteriorates the coronary circulation begins to fail and an escape mechanism functions otherwise death must follow

Variations in tonus of the infundibulum have been shown by electromanometric tracings before and at operation and will be demonstrated

Somewhat allied to this question of varying tonus in the infundibulum is another phenomenon seen in some cases of pulmonary valve stenosis with an intact septum After pulmonary valvotomy in some cases it can be demon trated that a secondary stenosis develops immediately in the infundibulum This is due to relief of the distension present behind the valve stenosis as *soon as the valve obstruction is relieved the walls* of the infundibulum fall together

This observation is fully illustrated and its significance discussed It is doubtless the cause of many of the so-called failures after trans ventricular valvotomy in which the pressure in the right ventricle remains too high The suggestion that these failures can be prevented by routine transarterial valvotomy under direct vision is probably not correct Additional infundibular resection may be effective but no always Perhaps shrinkage of the grossly hyper trophied muscle may set up a progressive *benign circle* These cases are a warning not to delay relief of pulmonary valve stenosis until gross muscle hypertrophy has occurred so as to make the ventricle muscle bound

Observations will also be presented on the secondary effects on the pulmonary circulation of relief of the stenosis in Fallot s tetralogy by direct operations It will be shown that there is no real truth in the criticism that a condition of Eisen menger s complex will be caused Reports will be given of catheter studies on the pulmonary circulation after direct operations Pulmonary flow is not necessarily related to pressure and examples will be given in which the pulmonary artery pressure remains below normal after very succes ful operation and yet the clinical and

functional result is perfect cyanosis and disability are totally relieved and the pulmonary blood flow is seen to be normal In other words the important factor is the pulmonary resistance which seems to remain low It may be that in later years after a long follow up we may observe an increase in pulmonary resistance and the later development of secondary pulmonary hypertension even with reversed flow and recurrence of cyanosis but so far no example of this has been seen The successful development of closure of the ventricular septal defect which will certainly be achieved should in any case prevent the onset of such changes

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Cor Pulmonale In Coal Miners

J GOUGH (Department of Pathology Welsh National School of Medicine Cardiff)

At the beginning of the present century the expectation of life of British coal miners was good and apart from accidents coal mining was regarded as a healthy occupation There has however been a change and when compared with other occupations the miner has lost his former advantage This loss has occurred progressively as shown by an analysis of the death rates at the census periods 1910 12 1921 23 and 1930 32 There was no census 1940-41 but the preliminary analysis* relating to the census of 1951 shows that the hewers and getters of coal in England and Wales now have a poor expectation of life compared with all occupied and retired men aged 20 64 the standard mortality ratio (154) being higher than for any of the other occupations analysed Included in the causes of the high death rate are myocardial degeneration (186 SMR) These are additional to deaths returned as due to rheumatic and coronary artery disease These myocardial cases undoubtedly include pulmonary heart disease which in miners in Wales is commonly due to massive pneumoconiosis (Gough 1947 Wells 1954) In 1000 consecutive autopsies on coal workers at the Welsh National School of Medicine in the period 1947 50 Dr W R L James found that 218 had died of cor pulmonale In most of these cases the heart disease resulted from massive pneumoconiosis The latter is associated with striking changes in the blood vessels severe obliterative arteritis occurring as a result of the extension of granulation tissue including dust bearing cells through the walls of the vessel Associated thrombosis may propagate from areas of massive fibrosis into larger branches of the pulmonary arteries A considerable part of the periphery of the pulmonary arterial tree thus becomes obliterated Commonly the main branches of the pulmonary arteries running towards the areas of massive fibrosis are of normal calibre for a few inches and then end abruptly having given off only a few small branches These changes have been described in detail by Wells (1955) working in the Medical School at Cardiff He also demonstrated the arterial obstruction radiologically at autopsy using radio opaque material injected into the pulmonary circulation

Lavenne (1951) concludes that the cardiac and respiratory causes of death in Belgian coal miners are the same as those in Wales Massive pneumoconiosis produces striking hypertrophy of the right ventricle This form of pulmonary heart disease has been investigated during life by Thoma (1948) who found radiological evidence of enlargement of the right ventricular outflow tract He (1951) also examined hearts from autopsies and showed that the wall of the right ventricle was greatly enlarged compared with that of the left He found that the cardiac failure is of low output type (1953)

Paper mounted sections of lung (Gough and Wentworth technique) have been used to study the coal miners lungs They show clearly the character and extent of the pneumoconiosis and of the accompanying emphysema The method has also been applied to ordinary cases of chronic bronchitis and of **status asthmaticus** It was unexpectedly found that spasmodic asthma even of very many years duration may not cause cor pulmonale The lungs in **status asthmaticus** showed over distension but did not show bullous emphysema and thus differed from lungs with chronic bronchitis The reason why the latter causes pulmonary hypertension is not certain but there are often associated changes in the bronchial arteries which may be the cause (Cudkowicz & Armstrong 1953)

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DISCUSSION

Professor McMICHAEL

Prof ssor D l ha indicated th compl ty of *physiological n lysis of the pulmonary c rcul tion in* the do s lung Most of u will agree that under his xperimental ondit on he h establ h d that the lung essel ha e son otor nnerv t n

There i a gre t d al of e id n e too n m n th t the lung arterioles h rs little ton They n g u r adily to c omm od te larg nc c of flow ithout much pressure ch n Thi pri c pl xplains the ucces of Brock operation n spite of absence of pressure alt r tion Lee and Dubois (1955) h e recently hown that th uptake of oxygen n the lung h pul atil ch ct — u gesting that the al eola c pill rie bl h with e h heart beat Durin the vasocon trictor re pon es which follow a V lsal a experiment the lun essel m k no *respon e in normal ubj ct Con id rable fluctuations* of pulmonary arterial pres u n m t al t ot may occur w th correspond ng n t on n the motion l *attitude of the p tie it M thonium drug oft n cause a* very cons d rable drop n pulmonary art rial p es ure beyond anythin expl ble on p i e con juence *of rd output chan es By u n the mean c r ul* t on time from ri ht atrium to the ar and mult neou a diac output estim t on w c n alcul te a central *ca dio-pulmonary blood olume With normal* o-motor ontrol thi olum d m n hes by about 250 c c on tanding upri ht (Gilmore et al 195) Methonium appears to aboli h thi constrict on of the lung es el Th observ t on of open ng and closing of lung cap llar in the cat mu t l th nk be an rtefact like some mil r observation on th glomerular cap llarie Such a phenom non would imply impair ntil tory efficiency unless the bronchioles are s multaneously and n the same area beha ing in an identical fashion Of pulmonary arteriolar vasocon tr ct on under pathological con dit ons there i no pos bl doubt Donald has ndicated the stages in its de elopm nt n mitr l tenos h e it m y b come quit extreme the pulmon ry arteri l pressure even exceeding the systemic Th s i p eced d b a tage at wh ch e en mild exerc se s ems to induce pulmonary asoconstriction M colle gues Goodw n Steiner and Lowe ha e ho n anatomicall that in mitral stenosis gross narrowing of the arteries occurs particularly in the lower part of the lung Thi localised d stribution of a cular narrow n may nter fere ith the val d ty or at least the repeatability of so-called pulmonary cap llary pressure readings

I rity of pulmonary capillary pressures over 30 mm Hg must be due to the fact that death or oedema is likely abo e this le el Hi her readings must be are without oedema unless capillary filtration d fferent from our usual concept on of i

The pulmonary hype ten on of emphysema is noth ng like so intense as that een in mitral stenosi It s of an p sod c char cter related to attack of bronchitis with exacerbat ons of anoxia and cyanosi (Moun ey et al 195) The mechani m here i obscure A fe years a o we thought th t a local react on of the pulmonary vessels to anoxia wa the an wer but mu h doubt has been ca t on th alidity of thi expl nation both by cl n al (F shman et al 1955) nd n mal experimental observat on (Naha et al 1954) *It is quite likel that the reaction a comple* re pon e to asphyxia in ol ng m ny humo al and n rvou mechan ms Th functional and variable *pulmon ry hypertension of ord nary bron h t* emphysema d ffers from the ascul r obstructi e type demonstr t d by Go gh in South Wale m n s

The lun vessel as a whole probably contain at any one moment 600 00 ml of blood Of this only bout 60 ml is undergoi acti e esp tory ga exchang in th alveoli (Rou hton 1945) The natom cal cap city of the al eolar capillaries must be n arly half the total volume in the lungs—pos bly 300 ml Dr Hugh Jones has su ested that this m y mean that under resting conditions acti e gas exchan completed in the prox mal end of the capillary and th t the rest is in reserve for higher dem nds e n e ercise When we apply the method of estimatin pulmonary blood olume to cardiac p t nts th re ults re most nteresting In left ventricular fa lure the cong tion of the lun s is assoc ated with an cr ase n pulmonary blood olume In n tral steno i no ncrease n lung blood content i d monstrable in p t of th increased ascular pre sures *It appe rs* that the lung e el as a whole ha lost th elastic expan ible properties—in short the essels are *ndurated as patholog ts ha e loo de cribed th m*

To um up som po nts n my e anescent scientific reed —1—I bel eve the lung ssels ha e an autonom nnervation *which comes nto action nd s demon* tr b e onl und pecial c rcumstances Th s i noth ng unu u l and has it counte part in for e ample *the problem of inn rvat on* of the plain muscle of the tomach

—I do not think the olume of blood flo in

through the b onchial artery anastomos s per se s likely to contribute seriously to pulmonary hyper t nsio I at nt ductus arteriosus c n exist for decades b fo e it b omes ompl c t d by pulmonary hyper ten on

3—Def ctive entilat n of th lun s from many au s may cause pulmonary asocon t ction wl ch e er ible f vent l t on c n be improved

4—The enormous capill ry capac ty of th lungs the no mally low pre su e nd the tremendous blood fl (total card ac output) make it qu te diffe nt n ts react on fron ny other part of the circulat on The f ctors con e n d n th whole concept of vascul r st nce m y d ffer cons derably n the s tem c nd pulmon ry rculatior s

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Dr MAURICE CAMPBELL

The am unt of tl e pulmon ry flow m u one of th mo t mpo t t fun t on of th lung Th r l ti n h of th to the pulmon ry pr u e th fo of g t terest Dr D ald h d us ed th in con ct on w tl e se and h po nt d out c nt a y to tl f nd g f om earlier ork rs th t in normal n th e often som l ght r se of pulmon y pre wh th card ac o tput d ubled l v

I uld l k to d w tt nt n to som t of th r l t on h p in ca es with left to ri ht shunt wl th j ulmon ry flow g e tly nc e sed d may ft n f four t m s normal I shall t ke x mpl s w tl a pat nt du tu b cause t the moment I am mo e f m l ith the results n th se The is no on t nt orr l t on of the le el of th pre r th ll o the flo or w th th g of th p t nt Th s m p opo t o t d ff rent ges f ll nto g eatly c e sed or mod rat ly i c e e l and no l pr ure but the e is a normal f ll n the pulmon ry r si t nce from h l lhood to adult l f th m in that r l t ly pe k ng th pulm n ry res t ce d e inc re e h ge in adults Th e low er m ny xcept n and n my th c old t pat nt with a p t nt duct aged 49 53 d 6 ll with l rge flow wh r between 50 nd 75 pe t of tl l ft e tricul r outp t is go ng th ough tl d ictu th p ssures we e qu t n m l At th other t three ch ld en bet een three nd fi e ye rs of age had sy tolı pressure betw n 70 and 86 not much below the r systemic pressu es but still w th la g left to right shunt

It is possibl that the pre sure l as ri n because these shunts v ould have be n so eno mou had th s not happ ned but the no p oof of this nd the e of th hunt was about the usual ran, Anoth r p nt wo th mph ne s that the pres u e s di ectly o r d rectly cau ed by the l ge flow bec use it c n be e ersed by clo ng th d ictus and in ll the th c case t wa found norm l at cath teriz t on less th n a yea after ope tion

The sam g neral pr n iples pply to trial nd entricular ptal defects In my e p nce the ri of pulmon ry pres rath mor ommon in m d lle aged p t nts w th atrial eptal d f ct and c y mu h mo common e en n ch ld en ith vent cular pt l defect prob bly bec u th large eptal defe t le ls to r e of pre e n th ght ntr cle and o n the pulmonary a t y more c ly th n the op ning of the p t nt ductu

The pulmon y hyperten on n mit al teno i lso pertin nt r th s con t on thou h t s of ourse p oduced n a d ff nt way Wh n the s rgeon is s t fied that he h carried ut good oper tion on the mitral l nd has in r d ll e p rtu e w ha e al s f und th t the p e re falls g eatly Thi i ho n by re cathet t on th ugh t too much to xpect that the i e of the pul non ry arteries w ll dim n h greatl l n th pre sure fall to d no m l

In spit of th tr h n h tolo i al p ctu n th lun s in nv es of pulmonary hype t n on o h ld b slow to a sume that th hype t n n v ble and gener lly the p t t hould b g n the b nefit of the doubt Th ppl l o n c ith left to ght hunt tho h n dult h r th h nt b c me e d ft m ny s r of n n pulmonary hypert ns on t s prob t ly often too l t d th condition h s b com rre ers ble It e ns howe un ec sa y to ccept the con ept of in nd p nd nt ongen t l pulmon y hyp rten ion and t tter to ssu th t n ch ld ll c c of pulmonary hypertens on e bl G n lly the fall in pr ssure occurs qu ckly ft p t nt du ts h be n clo ed but there i some d nc th t t m t k pl n tw st g the imm d ate f ll b ng d to m r fl x ch ng nd th lo f ll during the e t y ar or o being du to a g adu l e l of om of the h tolog al ha n th pulmo y t nol

Dr PAUL WOOD

Dr Don ld s gg tion that th l m tat on of th l ft trial pr s to 30 mm of me cur w th n r ng d g ees of m tr l t os s m gl t be c used by th incr ng d l tat n of th l ft t m nt f le be use th n o elat on betw en th e of th l ft atr um n l th d g ee of te c s or fo that m tt betwe n the e of th l ft tri m and th left trial pr ssu (Wood 1951)

Th re an be no quest on that th l ft atri l p u e ot nf quently ri e abo e th pl m osmot c p e u c nd on numb r of occ on w h ve recorded t fter x rc se t belw 50 a 1 60 nm of m ury without any ubjecti e d tre on th p t of the p tient o s obj ct e e d n of pulmon r d ma Dr Grah m Hayward n hi St

Cyres Lecture l st ye ır offered an explanation for thı phenomenon (Hayward 1955) *descrıb ng the de elopm nt of* phy ıcal barrier ın the ınterstitial tis ue bet een the pulmonary capillaries and alveoli so that at these high left atrıal pre ures pla ma may filter through the c pillarie but ıs held ın the inter stitıal space the lung becoming ery rıgıd ın th process thı interstitıal fluid ıs pre umably remo ed by the lymphatics and may be largely responsible for the radiological appearances which have been pre iously attributed to pulmonary enou congestion

There ıs on other point I would l ke to mention ın relation to mitr l steno ı n mely our n bility to demonstrate ny functioning an tomosi between pulmonary and bronchial vein I have tried to do thı ın t o w y —(1) By t king ample from the uperior vena c va above and below *the jun tion of* th zygos veın e should ha e been able to how an appreciable differ n e b tween th t so if oxygenated blood ın any amount a entering the zygos through *these anastomotic ch nnel* ın f ct *ho e er samples* fro n the e two ıte have lw ys been ıd ntıc l (2) By ınjecting dıodone ınto a perıpheral pulmonary artery through catheter edg d ın pos tion exc llent delin tion of tl art rı l nd v nous y tem of th segm nt con ern l ı olt ın d but out of a dozen u h experıment I w only onc ble to demon tr t filling of a bronchial vein th t ıd joıned the azygo

Turning no t Sır Russell Brock s r marks con rnıng K ıth th sı about the regulating fun tion of th infundibulum on the pulmon ry blood flow ın rep fles and amphıb I h t o ol servations to make which lend dd tion l r den e to th iew at le t ın re pe t of th ıtu tion ın F llots tetralogy I h e inve tig t d four se of Fallot tetralogy with yncopal attack ompl t lo of onsc ou nes occurring ın t o nd ınt ns cyanos nd f intnes thout los of consc ou n n the other t o In ll f ur c ses the murmur nd thrill either disappeared lıng ther or bec m mu h f nt r hıl th rterial oxyg n s turation dropp d no mo ly ı tually to ro ın on of them In c h ın t nc th y tem c *blood pressure rema ned norm l* o ıt s n highly ımpr b ble that a drop ın p pher l ascul r res t n was re ponsıbl for the nc a d right to left shunt In the most xtrem xample ıth a n r ero *arterı l oxygen tur tıon e ıs ed the ystem c* blood pressure from 100 to 150 mm H by me ns of m th drine but this made no d ffe enc whatever to th phy iological ituation

Th s cond cb rs tion onc rn the form of the pulmon ry arterial pre ure pulse ın F llot tetr logy In some cases the ınıt al rı of pre u e soc ated with ent ıcular systole ıs bruptly halt d a d suc d d by systolic trough It s u g ste l th t thı pheno menon wh ch at one tım s thou ht to b an rt f ct could well be e ult of a sudden shutting off of *th pulmon ry c rcul* tıon half way throu h syst le cau ed by funct onal losure of the nfund bulum

Since much has been said about pulmonary hyper t nsion I thought ıt would be s ll to how *a tabl* gı ing the actual frequen y with hich an extreme pulmonary vascul r resı tan e (10-30 units or 800-2400 dynes/sec /cm^{-5}) develops ın the chief condition ın hich su h a r action may occur In cons dering the frequency of this reaction one must be areful to ınclude only cases of critical se erity For example both patent ductus and entricular eptal defe t must be close on 1 cm ın d met r before an extreme pulmonary ascul r resı tance h an ch nce of

d eloping In these and ın cases of atrıal septal *defect* the communication has been considered critical ıf ıt has resulted ın a pulmonary blood flow at least *three times the systemic flow* or of course ın a raised pulmonary vascular re ıstance Mitral stenosis has been con ıdered *critical ıf the valve orifice* was around 1 x 0 5 cm The d gre of mitral ıncompetence ıs more d fficult to a ses b t *cases have been* included as critical ıf they *gave r se o certain* symptoms and clinical features *which would have demanded surg cal* relief had a suitable operation been available Chron c cor pulmonale was diagnosed on clinical ground and all case with an arterial oxygen saturation below 90% *at rest ha e been included provided* the patient was fr e from acute respiratory infection or asthma at the time The table shows the remarkable d fferences ın the fr quency of an extreme pulmonary vascular resı tan e (average 17 units) ın the e six groups ranging from no more than 5% ın severe mitral ıncompetence to 57 ın critical ventricular septal defect Ca e of Eisenmenger s complex atrıal septal defect with reverse hunt and patent ductus with re erse shunt have of course been included Left ventricular failure has been omitted from the table only because we have athetern ed too few of these cases to form any idea of the frequency of thı re ction The number of cases of primary pulmon ry hypertension ha been gı en for comparison The total number of all these se ere *pulmonary hypertensive case represents 1 3 per cent* of bout 10 000 c ses of card ova cular disease examined personally by the author o er the past se en or eight years

Just what determines the wide variation ın the rea t on of these different types of cases ıs unknown Th first three appear to be reacting to an initial *increa e of flow mitr l stenosis and ın ompetence to* rıse of left trial and pulmonary venous pressu e nd cor pulmonal to ano ıa An obvious unify ng pr nciple that might underlie all these ca es ı the *de elopment of act e pulmonary vaso constrict on ın* re pon e to a rise ın pulmonary arterial pres ure ho e er produced—a vicious circle mechanism—but th s ıs pure pecul tion No thesı purporting to explain actı e pulmon ry hyperten ıon can be valıd ho e unless ıt lso explains the varı ble beh ıour shown ın the table An inborn tendency to react n thı way has been po tul ted

Finally I would like to sho a slide illustratin a new technique for measuring the amount of function l a motor tone ın any case of pulmonary hyperten on o hat this can be s parated from any anatomical block ın the circulat on If approximately 1 mgm of acetylcholine ıs ınjected into the pulmonary artery ı the proxım l lumen of a doul le barrelled catheter a continuous record of the pulmonary artery pressur pulse can be obt ined by means of the second *b rrel* The do e of acetylcholine must be such that ıt ıs totally destroyed by the time ıt pa es throu h the pulmon ry ascul r bed and from trıal and error 1 to 1 5 mgm seem to be about rı ht The slide shows a con p cuou fall ın pulmonary arterial pressure com *menc ng* with the first heart beat following the sta t of the ınjection Owing to a sl ght rise ın card a output f om 4 5 to 6 litres per mınute the systemi blood pre sure has risen slightly and there ıs second ry slow ng *of th* heart rate this pro es that *the* acetylchol ne ıs not acting on the system c cı cula on A wholly selectı e action on the pulmonary ssel ı h ghly desirable hen ın estigating the *effe ts of pulmon ry* a od lators on the phy ology of any p rt of th c rcul tion

TABLE

FREQUENCY OF ACTIVE PULMONARY HYPERTENSION

	T tal No ases	No of cr t al case	P rcentag of crit cal cases		
			R normal	R high	R xtrem
Atr al s ptal defe t	197	100	75	9	16
V nt cular septal d fect	101	54	26	17	57
Patent ductus	133	45	38	24	38
M tr l steno		275	72	16	12
M tral ncompetence		58	86	9	5
Cor pulmonale		35	60	20	20
P mary pulm nary hyp t ns on		16	—	—	100

Cr t cal c ses for defin t on see text
R =Pulmonary vascul res stance see te t

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Dr J F GOODWIN

I hould l ke to make on o two observatio on th effect of methon um on th pulmon ry c culat on in acquired nd cong n t l types of pulmon ry hyper ten on

In mitral steno is my colle gue and I have shown that m thon um in a dosage wh h only *slightly lowe s* the y t m c rter al p e ur will cause a con d able f ll in the pulmonary rterial p e u e w thout s gni ficantly lt ng th c d c outp t or heart rate We feel th trongly suggesti e of release of neurogen c pulmonary vaso con tr ctor tone although we nnot with ce t nty e clude the pos b l ty th t th f ll n th pulmon ry arter al pressure is due to a shift in blood fr m the lu gs to the system c v scul b d W th nk th s nl k ly how v r n ew of the mu h great f ll in *pulmonary arterial pre sure than* n system c rter al p s Th f ll n p lmon y t l p s u e p oduced in m tral stenos aft r m thonium can also b p odu d to l ser e tent in p lmon ry hypert ion due to cor pulmon l O p i nce howe r with congenital type of pulm n ry hyp t n ion has been ry d ffe e t For ampl in p tient th atr al ept l d fe t w th ry h gh p lmonar arter l p ssu e and with a two w y shunt m th n um g en through the c di c cath t r f iled to lter the pulmon *ry rteri l pre u* Mu h fu ther wo k equi ed to dec d wh ther th d ff nce n re pon e betw n the two group i fo tuit or repr sent a d fferent type of pulm ra sc lar d sord

Dr W A BRISCOE

Professor Daly m nt one l n j ss g th ew h ld by som that somotor t it in th lu g f t occu r d was teleolog lly us le to the organism Th m ght be true f th lung we e e enly vent lated But th no m l lung sho s cons der ible d fferenc between th d gre s of vent l t on of it d fferent p rts som parts have only h lf the ent lation of oth rs Such a lu g w ll t nsfer o ygen and carbon d o de most effic ently f p rfusion is p oportional to ventil tion th o *ghout th lung Th would requ* that the blood perfus on to the less well entilated al eol be edu ed below th t to be expected if pe fu on were propo t on l to th qu te l rge vol im of the c al eoli Th us ny v somotor acti ity cu t l ng the p f on of l ss well entilated al eol would be t l ologically u eful New t chn ques of nterpre tation of m ing tud s and arterial blood analyses d loped n onjun t on w th Dr Cournand m y b t le to detect u d r perfu ion of le w ll ent l t d l *h in man*

There ha be n much discussion of pul non ry c p ll y p ssu I ho ld l k to utt r a warn ng bout samples of pulmonary cap llary blood taken w th a cath ter wedged in a small pulmonary a t ry Th blood h s b en p d through the wall of two al eoli and l a ent l t on pe fus on r t o about tw th norm l It annot therefore be reg rded represent tive of pulmon ry ou blood in c mpo t on

Wh n I was ery young we used to s t late at n ght d u ing the h gh ca d c output of some ca of co pulm n l nd t pos ble usefulnes to th p t nt At that time w s w o ly on teleolog cal j l n t on—An inc e se n d a o tput n a m n w th arter al u aturat on results n th d l v ry of mo blood d h e of mo o yg n to hi t u Howe r a n w usef lnes in th s h gh card c o tput m y be i ferred f m q ntit e tudy of e til tion pe fu on t on The tur t on of blood l ng n *al eolu hose w ll pe m t goo d ffu on of gase* os th m d pen l f r present purposes or th e

thing only —(1) *The in pired oxyg n ten ion* ( ) the ventilation perfu ion ratio of the al eolus (3) the oxygen satur tion of mixed enous blood Wh n the *entilation perfu ion ratio* in the norm l r nge or higher (about 1 0 or more) the satur tion of mixed venous blood h s very little influen e on the saturation *of the blood lea in* n l eolu But when the ventilation perfu ion ratio i low about 0 1 the satur tion of mix d venou blood an import nt deter minant of the atur tion of the blood le ing an lveolus

In men with art rial unsaturat on du to emph m there i a ery wid ange of ventilati n perfu ion ratios ithin the lung and larg volume of al eoli m y have r tio whi h around 0 1 only on thirti th f the ratio n the ell ventilated al eoli When rdi output i in re d t o parameters of blood ga tr n fer ar h in ed —(1) Ventilation perfu ion tios re reduc d ( ) the atur tion of mixed nou blood in r ased In the wo t entilated alveoli thi se nd factor greatly pre domin tes in import n nd l d to con d ril l in r e in th s tur t n of th blood lea n thes l eoli nd hen e n the s tu tion of mi d rteri l l ood In a typic l case of mphysem doubl ng of th rdi output woul l have r i ed rt ri l atur t on from 7 to 81

Thu e now see t o tel olog l xpl nation for h gh rdi output in o pulmonal There i the old t m e ffect b whi h *the mount of* uns tu at d blood d l d to th ti sues in r ased And there i no anoth r pulmonary eff ct b hi h th tu l oxyg n s *tur tion of th blood* *i* *in* *d*

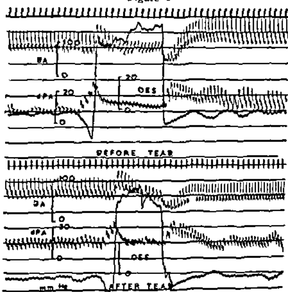
Dr G de J LEE

Dr d Burgh D ly ha di id d op n on re rding the presen e of vasomotor a tivity n the pulm nary scular ystem into three group —l the n hilist who on ider the y t m to be a pass on those who on ider th t omotor ctivity thou h p sent ve tig l and obscured by pa ive chang w th n the pulmonary ascular y t m nd 3 those who bel e e that asomotor hange pl y an active p rt n pulmonary homeo ta i He h ho n conclu ive e d nce ith rigorou l ontrolled n m l e pe iments to upport the act i t g oup I should l ke to discu s some data obtained th Professor Sharpey Schafer and *D Matthe (1954) at St Thom* Hospital from human tudie wh h n l ne me to hold an op nion of tentat e estigati m

It difficult to reach d fin te con lu ion bout the origin of pulmonary res tance change in man t i impo ible to control or mea u e t oke *olume We therefore compa ed simultaneou* pressure measu ements obtained from the y temic and pulmonary arter al sy te n u der circumstances *kno n to produce bvious system c oconstriction* Th use of Valsal a s m nœu re i a con en ent w y to do thi The brachial arte y p e sure changes are *cha acteri tic During the period that the intra* thor cic pres ure i ra sed while Valsal a manœuvre is maintained there is an initial squee e mparted to *the thoracic aorta wh h p oduces a short lived sharp* ri e in the arterial pressure Then as heart fill ng is impa red the stroke olume progre ely d reases *and pulse and mean pressures fall* With the release of the Valsal a the mpairment of enous eturn to the heart ceases and there s rap d nc ea e i t oke *volume* Th s is associated w th a marked rise n both pulse and mean pressures in the systemic artery wh ch sometimes termed the overshoot Part of th s ri e in pressure is due to changes in *stroke volume* but vasoconstriction induced by the period of low pulse p es ure during Valsalva s manœuvre is also responsible This period of *vasoconstriction followin* Valsal a s manœuvre can be demonstrated by a fall n fore rm blood flow mea ured by venous occlusion plethysmography (Sharpey Schafer *1953*)

The systemic arterial pres ure was compared with the effective pulmonary artery pressure obtained by a differential manometer *recording the difference* bet veen th pulmonary artery pres ure via cardiac catheter nd the intrathoracic pres u e measured from a water filled catheter situated *in th oesophagu* (Dornhorst and Leathart 195) The systemic re pon es have already been m ntioned In the pul monary artery a similar rise in *pre sure also occurs* following release of the Val alva manœuvre (F ure 1) It d ffers from the brachial a tery response in th t

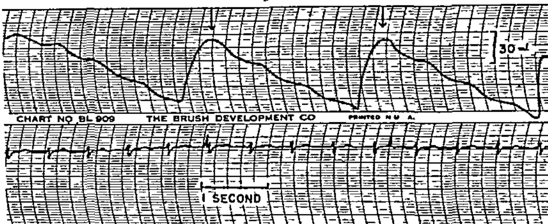
Figure 1



F gure 1 The effect of Valsalva s manœu re on brachial (BA) effective pulmonary artery (dPA) and intra oesophageal pressure (OES) There i a marked *r se n b achial artery pressure follo in* Valsal a s manœuvre Th s s abolished by T E A B The p l monary artery p essure also rises th s rise is in *dependent of g nglion* blockade with T E A B

pulse pre sure chang i ma ked and the phase of re piration lso affects the mean and pulse pre ure being lower in expiration and h ghe in in p rat on These changes sug st that stroke output cha es are the e ent ch efly concerned with altern the pul monary a t ry p essure As the troke volum c nnot be measured or controlled it was dec d d a n alternative to block the poss ble asoconstrictor *eff ts* also present by using Tetraethyl ammoni n br m de An intravenous dose suff c ent to aboli h post V ls l a soconstr ct on in the sy temi artery was *used Th s* had vi tually no effect on the pulmonary artery pres ure hanges sugge ting th t flow e erts were

F gu 2



Γ ure R cord obtained du n⁻ I ath hold g aft r N O nhalation Flethysmograph pressure above al I rated ol m change I C G hown belo I I thy mog ph nt d to atm pheric pressure at th arrows

ŀr l in n ting Ih w f rth r c nfirm d l y mil r nt occurring in r ght tr al fill ng pre

W th fore c nclud d that n n mal m troke olum change p p d rate s nfluenc ng th pul mon y a t r al pre u nd that asomoto ff t a not suff ntly tiv to p od e ch n e 1 n t Il l y the te hn q d scr l ed

It m y well be that when the p lmona y t l s t m o c ted f m a low p re to h gh ŀr y tem by d sease th asocon t tor effects be o in t t Th would e pl in the l k of ŀ nse n o r no m l ubj ts comp d with th effect s of H ametho ium in l wering pulmo ary t y pre th t Dr Goodw n has j t descr l d

I omp t ely hort scular s t m u h a th ŀulmo ary l t on with th ppa ntly l w d gr of v sc lar t n ity j t d mo trated it i re ll t pre me th t the ŀ l at l ty of blood fl w thro gh th m in pulmon ry arter wo ld rema n n th p lm n ry p llary system

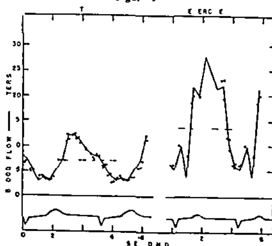
R ently n D Comroe d p rtm nt at th Un rsity of P n vl an Dr Dubo s and I wer bl t t t the hypoth g m d f t on of I kl N t ous O d t h que for me ir ng l ng H l fl w i m n to flow in t tan u flo nt to l c l ul t d (Lee and Dubois 1955)

If t fin qu rqu ed that th su l ject s t in lose l t ly pl thy m gr ph Th d ff rent l pres re betw th h mbe n l m l r ompensat ng h the wa m n u d Th y t m w ju red t lt i tle t t ure ent will th l dy pl th i g ph—free f om no se rt f t E t w t m l g in t tl ul ject s I C C Aft o trol per l tl l j ct took l eath of 100 nit o o l d h ld h s t th w th th gl tt open A tl g w b bed f om th l ngs into th blood flow ng th gh th p lm n ry c p ll the tot l olum of g ses i th lungs nd h n th pl thysmogr ph p es ur decre sed prod a f ll in pl thy mog ph pre re Th a cont ou re o d of n tro o l upt k wa ol t n d (Figure) F om pired e s mpl n l know g th sol t l ty of

N O in blood tl n tant n ou p lm o ary capill ry blood flow rate was calcul ted (F gure 3)

Th apillary blood flow w s found to be h ghly ŀul t l At e t th peak blo d flow t was in the region of l 5 l tre /m n Th s occurred at the tim of th T wa e of the E C G Th slow t blood flow rate occurr d in th reg on of the QT nt rval and

F gur 3



I gur 3 In t nt n ou p lmon ry capill ry l lood fl w t at st n l aft e re se 7e o t m l itr rily taken th R w e of th E C G —shown bel w ch flow cur Closed ircl p sent n t nt u fl w t at h 0 04 sec f om fo secut h t cycl Sol d l p sent th erag ta t in o fl w t Dott d l rep esent m n c l outp t pe m te

about 3 litre /min Aft r moderate exer ise the pe k flo rose to pproximately 8 litre /min the lowest flow rate being bout 6 litre /min

These en rmous ch nge in flow rate with each heart beat su est that th pulmonary capillary and rter olar sy tem mu t be ery ea ily d tensible whether this is pa ive or d pends upon critical opening pre u e r main to be det rm ned The delay in peak capill ry blood flow to the region in t m with th T way e when th pulmonary v l e i ju t clo ing i pre umably due to the elastance of the vascular y tem b tw en pulmonary valve and pulmon ry apill ry

Oxygen uptake by th lung is aff cted by the variable c pillary blood flow and its uptake from the lung i al o highly puls t le (Lee and Semple 1955) The pr sent on ept of ga diffu on nd ventilation perfu on r l t n hi within the lung whi h in the p t has umed n t nt ap ll ry blood flow re th f r lik ly t be ffected nd th se re being m t t d

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Dr W WHITAKER

Working in Dr Bro n Department and in the Un ersity Dep tment of M dicine n Sheffield Dr H ath and I have tud ed patient ith on enital and acquir d heart disea and h v amined th an tomi l h n in the pulmonary blood es l in relation t p lmona y artery blood p u W have found a low oci tion

When the pulm nary artery mean blood pre sure are norm l or not over 50 mm Hg the pulmonary vess l a e u u lly normal When the pre ure i of the order 50 70 mm Hg a me ha is found i the pulmonary arterioles and this we egard as the funda mental histological feature of pulmonary hyperten on

Th first l de shows four pulmonary rter oles (l less th n 100 u in d ameter) from a normal p t nt nd from three patient w th **moderately seve e pulmonary hype tension** The norm l arteriole h no med a the all on t n of a ngle elastic l mina betw en a thin d ent t a and intima th oc ion l nd du l musc l cell Th other thre art roles (d op th pul nonary hypert n on p e ure 0 mm patent du tu arte u pressure 65 mm m tral t nos p es ure 74 mm) all how a d fin te med The muscular pulm n r arter e (100 to 1000 u) from patients th **moderately s v re pulmonary hypert ns on** usually how m di l hyper trophy and an ab orm al mount of ub nt mal fibrou tissue but these changes are n t so consistently found a th abnormal media n th pulmon ry a teriol s

In **vere pulmonary hypertens on** here the pul monary pre ures ap p oa n or ex eed th s t mic pres ure the pulmon ry ve sel a e g ossly abnormal The arte oles and muscul r pulmon ry rter ho med al hypertrophy and subintimal proliferation of fibro s tissue with occlu ion and recanalisation of the lumen Arteriolar necrosis is occasionally found in association with severe pulmonary hypertension (slide shown) The final slide shows an unusual feature ob erved in a patient with ventricular septal defect complicated by severe pulmonary hypertens on throughout the sections aneurysms appeared from the alls of the muscular pulmonary arteries shown on ser al section to be aneurysmal dilatations of branch s of the arteries

In patients with severe pulmonary hyperten ion and extensive pulmonary vascular d sease the signs of pul monary hypertension dominate the cl nical picture and t may well be impossible without specialised inves tigations to recognise such underlying l sions as atrial septal d fect ventr ular septal defect patent ductus arter o u or mitral stenosis or to e clude idiopathic pulmonary hyperten ion It seems reasonable to su gest that such patients with severe pulmonary hype ten ion havin similar extensive char cteri tic pul mon ry va cular abnormalities should be recognised uffe ing from hypertensi e pulmonary vascular d sea e

Dr D V BATES

To a clinical respiratory physiologist provocative marks and ideas have been shot into the air today l ke clay pigeons and it is hard to kno where to hoot f rst There are hov ever four points worth mentionin First Profes or McMich el may be nte e ted to know that the change in pulmonary blood volume v th posture that he mentioned has been sho n by recent v ork at St Ba tholome s and n Philad lph a to be due at l ast in part to an actual increa e in the o ume of blood round the alveoli Second I must take i sue th him over the actual volume of blood around the al eoli at any one time He mentioned a figu e of ¾ of a litre of blood nd contra ted thi ith the fi ure of 60-90 c c obtained by Roughton in 1945 A recent report of Rou hton s ork ha shown that the order of error in his est mate of 60 c c i small— and at the moment I think this e iden e to be preferred to that supporting a f gure of 750 c c Thirdly I think it very mportant to d tinguish carefull betw en pulmonary hyperten on au ed by different mechanisms We h e recently h d an opportun y o tudy a patient w th prim ry pulmonary hyperten on with a very h gh pulmonary rtery pres u e In thi patient there as no bnormal lung stiffness and no chan e in pulmo ary gas d ffusi n Contr st th with mitral stenos s and you wil r ali e that in mitral steno s the pulmonary capillary bed lies between the obstruct on and the righ ventricl v herea n primary pulmon ry hyper t nsion the le ion is s tuated b t een the capillary bed and the entricle The e distinct ons seem to me important and perhaps ha e not be n suffic ently s d Finally on the matter of the observation that pulm nary capillary pressur m y ex eed the ncot c plasma p s ure w thout pulmona y oed m With my colleague Dr McIlroy we w re ec ntly measuring the physical p operties of the lun nd the diffusing c pacity in a man who had had a p eumonectomy He wa walkin at about 3 m les p r hour without d tres hen we noticed that the lung was be oming progressi ely stiffer i th th man nten nce of a normal m nute lar nd the gas d ffus n was stead ly falling These are the ch nges

of d elop ng pulmonary oedema We stopped the treadmill the patient walked back to h cha r and ther was at no time clinic l e idence of pulmonary oed m I menti n this patient to illustrate the possib l ty that gn fic nt tran udation may occur ac oss the lun cap llaries without this being clin cally obvious as gros pulmon y oedema

Professor MELVILLE ARNOTT

Emphas was placed on the f ct that th elevat on of pulmon y capillary pres ure to a level above the oncotic p e u might not be a my teriou a it fi t ppears It must frequently h pp n during state of pulmonary oedema th t the p sure is r sed well abo e on ot c pre u e for prol nged p riods and th t cons de ble amount of protein r h fluid escape into the l oli Only a fr ction of this is coughed up the m n bulk of t h ing to t removed a the lung nd lymph t cs It might w ll be that the impo t nt f cto us ng severe pulmonary oed ma s a gradual det oration of th lung lymphat c n the r c p c ty t r mo e fluid Ind d there m ght be the develop ment in the l g of a sort of ch onc ndurative t t som what an logous to the lymph oedema th t oc urs in the y tem c rculat on n ar ose n f th lo l mb an l t f l n s

Sir RUSSELL BROCK

I would lik to congratulate Professo Liebo on th pec m n h ch h showed us n his add Those of us who h e kn wn h s work have dmired it for many y rs Th s one aspect of h s demon t t on on ond ry pulmonary y t m c commun tio that I would l ke to d scu s He ind cat d that such second y commun at ons may b of mpo tance in regard to th as ularisation of the myocard um of th ventricles in c es of myocardi l ischa mia To support this l e d sc ib d c rt n forms of ne s ls which l e h ol se d and demonstrated Th one ar ety of thi secondary ve sel f mat on wh ch he efe red to only b fly nd wh ch I would l k h m to cl rify Th t th form tion of d ct n stomose between the ve el of the l g nd the co on ry sel on th u face of the entricles He nd ted that n operation of c d o-pn umonope y might be of on d r bl alue in provid g u ful and m po t nt second y blood s pply to the d s ased myoc r lium Th s ob ously a matter of fu da n t l mport e n relation to the p nt ttent on th t is be ng p d to u gic l method of impro i g o m t g t g c o y sch m Tho of u who h ope t d on th h art and lung may h e obser ed ct in f tu th t I h e obse d myself To t nce n of p lmonary stenos s nd particu l rl in a of e ere pulmon y t no mo t n to tr a the presence of the l rge coll teral c rculation only too ol ou d esp c lly s th so n c in wh ch a se o d op ration t ng perform d H re th adl es bet n th ch t w ll nd th lu g full of l rg sel wh ch bled so freely wl en th y d d d th t the p ti nt m y be s ngu ated d t n a be n cess ry to b ndon tl e operat on How r it h not been my e peri nce to ol rs m l free w v sel f rm t on between tl lu g and the urf of th heart itself Professor Liebow describe l the retro c rdiac an stomot c v ssels which he emphasi ed and which re similar in character to the ana tomose between the lung and the chest wall That s anastomo e between the coronary c rculat on and mediast nal v sels These vessels he displayed cl arly and pre ely in all h s spec mens He did not show qu te so cl arly however the vessels th t occu between the surface of the lung and th surface of th entr cles I ha e re op rated on a consid able number of c es of heart di se both cong n tal and acqu ed lesions such as mitral stenos and I have fa led to observe any vasculari ation of mportan e in adhesion bet een the su face of th heart nd the pericard um or the adjacent lung In f ct it is my p ct ce when ope at ng on a h art ca e as a fi t step to fre the whole of the he rt from th p ricard um in o der to be bl to pply card ac m sage eff cently hould it pro e n cessary In doing th s fre ng unl one di id f) nstance a co onary es l there no ble d ng Th re i no evidence of new e el In addit on when I con lude n operation on the hea t I the pericardium loosely o that apertures rem n At re ope at on the aperture till pe st can b s ly recogn d and through them th u f ce of th hea t i n d rect cont ct with the lung t e Agai I would emph s e that it i not u ual to find any ascula conn ct ons acro th s space Th t s th p oblem th t ornes m

Professor LIEBOW

When Sir Ru ll Brock repo ts on an op t ve fi di n m n that appea s ncompatible w th th p ments that ha e b en ported he must be g en th clo t tt nt on The transperic d al ollateral w r not emphas sed during the pre nt t on s nce thi was the xp ted find ng it was the demon tration of the t o d oll t ral that was not expect l nd that was therefore presented in great d t l

In his op t on on man Sir Russell was deal ng eith w th norm l lun s or with lungs in wh ch the oll teral blood supply h d lready b com e t b lish d In th pr sent xperiments howe e th pul monary artery l gat d at the t m of th rd o p um opexy und th s rcumstances the lung at on e becomes a very blood thirsty o g n A part of thi th t t fi d by p n f th no m l bron h al t l s pply from th hilum the remainder come f om th p on of es el th t e fo m d as g nul t on t su w th n adh ons In th ours of t m thes enl ge g eatly to the s e of arterial es l nd the m croscop st t qu te com p t bl Th y qu e el tic ti sue and muscle as would be expected of l of rt l type and simi lar The actual tran pericard al oll t l th t w ho n on the sc n had cros sect onal diam t of pp o imately l mm Num ou m ll e sels w ob n d n ll of th h arts thus treated by d opneu ionope y after l gatur of th pulmonary tery Th sel n cl l ger than thos fou l n o d nary lhes on fo e mpl wh n the per ard al m d to form g anulation t s ft njection of silica du t Un ler th r m t ces they r too small to be nject d with th p l t u d n th prep t on l the c t

It s s rpr ng that n th pr se t periment n actu l t a f of blood from the coll t l rcula tion to the coron ry ter wa d mo t ated wh n t m ght be pected that th blood pres r in th oron ry t s ho ld ed that n th coll terals

Th mo t rea onable explan tion s that the pulse p es ure w in the two arter al ystem ar out of phase

Professor WALMSLEY

Si Russell Brock ha m de ref ren e to the presence of the bulbu ordis as a separate chamber of the heart in fish and in connection with this I hould like to m ke t o remark The first i that in many Teleostean fish the bulbus cordis is largely sup pressed and cannot be identified as a separate chambe coincid nt with thi suppression there i a remarkable development of the elastic tissue of the adjacent part of the entral orta Secondly that in n ubjacent to the myocard um of the bulbu cord of cartilaginous fish there i a ell d fined lam na of ela tic tissue wh ch wh n traced headward becom s ontinuou th the elastic ti ue of th entr l ort

In the examin t on of foet l nd dult human he t I have ne er been able to id nt fy the infundi bulum as well d m rcated part of th right ven tr le but I have noted that t interior s mooth hich s in triking contrast to the tr becul ted in te io of the right ventricl p oper

Dr C M FLETCHER

I have a question to ask and a co nment to make about Professor Gou h s paper

The Quest on—How can a fibrou mass occupying not more than o th rd at the most of the lungs produce pulmonary hypertension no matter how se er ly affected ar the vessels in the mass if as appears to be in om cases the rest of the lung is almost normal?

The Comment—P ofessor Gou h told us that the SMR for Myocardi l degeneration n 1951 was 186 for coal hewer and getters and 110 for other mine workers but these figures cannot be assumed to indi cate an occup t onal or gin for the excess mortality of these workers for their w es have an even h gher SMR n mely 1 nd 179

Professor GOUGH

In the obstructi e f rm of pulmonary hypertens on in massi e pneumoconio i the blood vessels in the masses may be almost all dest oyed but the main essel l ading to th masses not only emain patent but a dilat d Th r ght heart ha thu the mechani al disad anta e of ma ntain ng th column of blood against ons l rabl res sta ice a only a ery small proport on of blood pumped into these essels can find a periph al way out

With ega d to Dr Flet he omment on the death ates my theme wa that th re ha been a relat ve d t rioration in the expectation of life of co l miners s nce th b ginn ng of this century when compared with other male occupation and it an be of little consolation to these miners if they a e now nearly as badly off as their unhealthy wives (SMR 1951 All causes He ers and getters of coal 153 their wi es 148)

Dr DOSS

I want to make a few remarks about pulmonary hypertension in Egypt caused by schistosomias s The ova *of the Bilharzial worm from the bladder region* pass to the lung and are caught in the arterioles of between 50 and 100 u They penetrate the e vessels producin an *inflammatory reaction with endarteritis* and often in addition an angiomatous formation We u ed to think that these an oma ous formations connected the occluded vessels with the pulmonary veins or the bronch al arteries But I see that in the d monstrations here Dr Bird has followed up similar ang omatous formations in another condition of pulmonary hypertensio 1 and has found they interrupt *the pro imal and distal parts of the same essel* One of the characteristic features of our cases is the peripheral oligaemia as seen in the X ray picture The vess ls from the hilum to about two thirds towards th periphery are seen to be dilated and then the vessel markings d sappear *This would seem to* ndi ate that peripheral to the obstruction p oduced by the inflammatory reaction no blood is flowing *As some speaker pointed out a little while ago* it seems strange that a localised le ion like the ones we observed could cause pulmonary hype tension *In many cases the lesion produced by the Bilhar al ova* are quite widespread nd it would seem understandable that n such cases they would produce pulmonary hyp rt n on But n other cases the lesion is a very limit d and restricted one and yet even n those cases some degree of p lmonary hypertension is very often present This ra sed the possibility of some functional factor playing a *role* so we embarked on the following experiments We injected between 25 and 50 mg of hexamethonium by cardiac cathete into a branch of the pulmonary artery and noted *the mean artery* pressu es befor and after the adm nistration After hexamethonium the pressure d opped cons d rably in *a few minutes sometimes dropping from as h gh as 90 to as low as* 5 or 30 mm of mercury In normal control the pressure dropped from an average of about *13 or 15 mean artery* pressu e to 8 or 9 or 10 mm of mercury It was ob ious from this the efore that in the cases with pulmonary hypertension the p es r was partly due to a structural narro vin but mo ly due to an ncrease in the pulmonary asomotor ton The poss bility that changes in the cardiac output had caused this drop was ruled out by the fact that very l ttle change f any occurred in the cardiac *output* Thi corresponds with the wo k of Pro esso McM hael who also showed n some pat ents that the in ction of hexamethon um *d d not brin* about any chan e of c diac output althou h it d d brin bout a drop of the pulmonary rtery p essure We are at present investigating the *noxia present in those pat ents with* th h ghest pulmonary artery pre su es

Finally I would comment on the Cha man s re nark this mo ning that Servetu in the 17th c ntury was the first to describe the pulmonary c culat *on In* 1948 a paper given to the National Congress of Physiology in Paris showed that an Arab phys c an Ibn al Nafiss *had described the pulmonary* circulation in the 11th century and su e t d that S vetus had known th s work

Dr K W DONALD

Dr K W Donald pointed out th t *Prof sso* M Mchael s contention that underventil t o of blood

with cy nosi would occu with ariable nd pha c alteration n pulmonary capillary flow was not neces a ly tru as such ch nges m y not alter the al ola ent lation perfu on rel tion h p and that in any case pp opriat ch nges in local entilation m y l o occur H observation th t r cent e t mate of blood vol me in th pulmonary cap ll rie were f r greater th n sugg sted by I ou hton s c lculat d fi u e could n t be a ounted for by invok ng that part of th c pill y bed wh re under normal co d t on lmost complete gaseou equil brium h d been eached and no ig fi ant g s e ch nge wa taking place In d ffu on stud c u ing arbon mono d the ga tr fe occurs o r the whole length of the capill ry

W th reg d to Dr M urice C mpbell s intere t ng ob v t ons concerning the con d rabl fall n pulmonary art al pre u e after m tral l ulotomy t wa *mport nt to d f n how much of th s was du* to f ll of pre u in th left t ium It as also t l r fly rt n that the right entr le of many of the e p t ents fter operation was do n con derably mo e wo k as lthough the was usually som decrease of pulmonary arterial pressur the c rdiac output was far g eater th n befo e operat on both at rest and on xerci e Furthe the e patient were able to e rt th msel s ons der bly throu hout th day

Dr Donald also stated that he f lt the importanc of the direct l ft atri l pre su e reco d n s nd their comparison w th wedge p e sure had not been fully appreciated as without such e idence wed e pre *ures and all estimates of pulmon ry* v scular e tance usin th s v lues would m an v y little

There v s one hypothesis concerning the import anc of pulmonary v so-const ict on in d d stat that had not been mention d It as po ible that muscle hyp rtrophy of th ve sel v ith abnormally in ased ular p es ures m y cause a d gre of flecti a o con trict on that ould n t b po bl n the h lthy l ng

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Studies Of Left Auricular Pressures In Man

P R ALLISON (Radcliffe Infirmary Oxford)

The position of the left auricle below and between the two main bronchi makes it easily accessible to puncture through the bronchoscope We have already done this on 157 patients with out any resulting complication In the first place the investigation was undertaken in an attempt to distinguish between mitral stenosis and mitral incompetence and also in the hope that the findings might provide a pre operative assessment of the degree of stenosis Only in more recent months has puncture of the pulmonary artery and the aorta—by the same method and at the same time—been made a routine procedure in the examination of mitral disease

Our clinic has been something of a general pool for heart disease but there has been some selection inasmuch as the patients were referred for possible surgical treatment Apart from this all patients with mitral disease had a left auricular puncture except for the occasional one where mitral stenosis was associated with pregnancy or easily induced pulmonary œdema

The use of a needle fixed to a Jackson suction cannula and connected to a Hansen capacitance manometer has already been described (Allison and Linden 1953) Since then thicker polythene tube has been used between the cannula and the manometer with a reduction in the number of artefacts but attempts to do away with the tube altogether so that the manometer was attached directly to the cannula were unsuccessful because the apparatus became too heavy to use with accuracy If the tubing is allowed to oscillate at all marked irregularities appear in the tracing

A few normal curves were obtained by auri cular puncture of patients being bronchoscoped for bronchial carcinoma Series of tracings were then taken from patients both fibrillating and in normal rhythm with mitral stenosis incompet ence or with mixed lesions It seems possible to draw a few deductions from the study of these 157 curves done so far

Although the general shape of the curve may suggest either stenosis or incompetence no reliance is to be placed on this Any conclusions must be based on a mathematical analysis of the curve rather than on its general form In this particular the formula for the mitral value

$$\frac{Pv - Pz}{Pv} \times 100$$

as suggested by Linden (Allison and Linden 1955) has proved to be much more reliable than the analysis used by Facquet (1954) or the formula suggested by Wood and Owen (1955) Linden s formula has been brought up to date on this series and in only very few patients were the operative findings at variance with the *formula In these record there are occasional* example in which the shape of the curve sug

gested regurgitation but which on analysis indicated stenosis and where operation confirmed the result of the analysis Similarly one or two typical looking stenotic curves proved both on analysis and at operation to be regurgitant It is wrong therefore to speak of typical stenotic or typical regurgitant curves from the shape alone The relation of the curve to the base line is all important

The second deduction is that the most reliable curves are obtained with the slower heart rates This is in agreement with Facquet (1954) who suggests that the heart rate should be kept below 100 if possible To achieve this digitalis and morphia may be necessary atropine should be avoided and probably most important a close relationship and understanding should be established between patient and operator to reduce fear The bronchoscopy should be performed gently and smoothly

The third deduction is that the diseased mitral valve is not always either stenotic or incompetent During most of the cycles a stenosed valve may be quite competent and then during one or two beats regurgitation may occur This has been observed only in a fibrillating heart and occasional incompetence may be apparent after a long diastole The phenomenon is certainly influenced by heart rate and the findings on the tracing can often be confirmed by the finger in the left auricle at operation

It may be said that the diagnosis of mitral stenosis can usually be made fairly accurately by other means without the need of left auricular puncture This is undoubtedly true but there are occasions in our experience when this has not been so An example is D G a very fat woman of 44 years who had been a nursing sister now *bedridden from breathlessness She had had* numerous attacks of heart failure and two large hæmoptyses *She was very cyanosed the heart* was greatly enlarged and the only consistent *abnormal physical* sign was a systolic murmur at the apex If it had not been for her own *insistence* on surgery she would never have been sent to the clinic By bronchoscopic examination her pressures were found to be —Left auricle 52/32 pulmonary artery 87/52 and aorta 180/120 in cms of water This gave a mitral valve of 31 which for a fibrillating heart meant stenosis At operation uncomplicated tight stenosis was found and a good split back to the ring obtained at both commissures with no trace of incompetence

The relations of the left auricular pressure to pulmonary arterial and aortic pressure at bronchoscopy and later with an open thoracotomy were noted in this and a few other *recent patients This work* perhaps merits comment even at this early stage (see table)

D G 44 years T ght mitral stenosis			
	P e ur in cms H_2O		
	Left aur cle	Pulmonary artery	Aorta
B oncho cop c	52/3	87/52	180/1 0
Open thorax *before* comm ssurotomy	30/13	82/45	68/34
Open tho ax after commissurotomy	14/4	37/13	60/33

In this patient the anæsthesia and the thoracotomy lowered the left auricular pressure appreciably the aortic pressure drastically and the pulmonary artery pressure not at all After commissurotomy the *left* auricular and pulmonary artery pressures fell to normal without any improvement of aortic pressure

In another patient a left auricular pressure taken through the bronchoscope was *60/29* and at open thoracotomy *50/22* which represented very *little fall* if any *In this* same heart a preoperative pressure in the pulmonary artery both at *bronchoscopic puncture and cardiac* catheterization was 160/80 falling at thoracotomy *to 90/47 whereas the aortic pressure fell from* 130/90 to 64/41 It seems that if the left *auricular pressure* is *high* from mechanical obstruction it is not grossly affected by the influences that may bring the aortic pressure tottering down with or without a fall of pulmonary artery pressure In short the higher the left auricular pressure the less dependent it is on extraneous circumstances other than relief of the mitral obstruction One patient with a *left* auricular pressure of 26/10 had only very mild obstruction and his pressure *fell from this to* 6/1 at operation without any fall at all in either aortic or pulmonary artery *pressure A* corollary of these findings is that deductions drawn from single estimations *of left auricular* pressure without relation to the conditions under which they *are taken are as meaningless* as those taken from similar observations on arterial pressure which is about what we would expect

On the very few observations made so far *and for obvious* reasons these have been confined to patients with mitral disease hoping for treat

ment it seems likely that the left auricular measurements made by direct puncture bear a close relation to the pulmonary wedge pressures when the left auricular pressure is high It does not follow by any means that the same applies when the left auricular pressure is low These are problems that need further investigation

Another question of interest was whether the pressure in the left auricle at bronchoscopy gave any indication of the degree of stenosis The answer to this was likely to be somewhat vague inasmuch as the estimation of the effective size of the mitral orifice at operation could lay no claim to accuracy The variation of the flow with the fourth power of the radius greatly increased the inaccuracies of estimation of the size of the opening Without being able therefore to present a series of figures on an elegant but deceptive graph one can still say that the highest figures of left auricular pressure indicated the tightest stenoses Certain it is that with typical signs of mitral stenosis no matter what the symptoms there is no indication for operation on the valve if the left auricular pressure is low The possibility that in such patients the symptoms have a psychological basis or arise from pulmonary disease and not mitral obstruction must always be carefully considered

The relation in this series of the left auricular pressure measurement to the lymphatic flow from the lungs as indicated by the fine horizontal lines in the costophrenic angle is being investigated by Rossall and Gunning and will shortly be reported

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Vasculitis In The Lung

A C LENDRUM (Department of Pathology Queen s College Dundee)

The understanding of the pathology of the lung in cases of mitral stenosis had a curiously static history until some 15 years ago Till then it was little more than venous congestion and brown induration Then it came to be realised that the distribution of the hæmosiderin containing phagocytes is sometimes strikingly focal (Lancet 1952) and this led to a fresh interest in the pulmonary circulation Next came the observation that in some cases of mitral stenosis the arteries show changes recalling polyarteritis nodosa and close on the heels of this cardiac catheterisation arrived

This so called arteritis merits attention because on our conception of this condition will depend some of our speculation on the pulmonary circulation Two main lines of thought have arisen One group regard the changes as comparable with those occurring in malignant hypertension since the changes had been observed in cases showing the morbid anatomical features of pulmonary hypertension The other group while admitting the presence of hypertension regard the histological changes as more closely resembling those in polyarteritis nodosa This impasse has stimulated further study of these and comparable conditions and a new viewpoint is now offered

Firstly it may be noted here that the lung showing arteritis or better vasculosis may have no focal hæmosiderosis and in one case in which both abnormalities were present there was an absence of vasculosis only in the regions where there was obvious focal hæmosiderosis

The vasculosis is seen as a deposition of fibrin in the walls of the pulmonary arteries ranging from 450 μ down to those of 50 μ These sizes are measured on involved arteries and arterioles but the affection may well have led to widening To summarise my interpretation of the changes fibrinogen enters from the lumen and fibrin is deposited under the endothelium Where the intima is thickened it is possible to see a piling up of the fibrin on the inner side of the internal elastic lamina in the same way as Anitschkow (1933) noticed with the lipoids in cases of experimental hypersterolæmia The fibrin then appears to break through the elastica traverse the media and again be partially held up at the external elastica with the result that it may

spread laterally for quite a distance on the inner side of this membrane. Finally it erupts through and fans out in the adventitia. One presumes of course that the substance that spreads is fibrinogen: the material one observes gives the staining reactions of fibrin (particularly by the picro-Mallory method). In some of the affected vessels there is now seen a gathering of cells, many of which are polymorphs, very few are eosinophils, and some are recognisable only as nuclei which show extraordinary elongation and distortion to tadpole forms or angled matchsticks. These distorted nuclei are a very unusual and striking feature.

FIBRINOUS VASCULOSIS

Static type	Infarction and torsion
Hypertensive type	Malignant hypertension
Hyperergic type	Drug induced vascular disease Possibly also focal polyarteritis nodosa

Study of a series of other vascular lesions has led to the discovery that a similarly distributed deposition of fibrin occurs in cases of drug induced vascular disease (hypersensitivity angiitis Zeek) in the kidney of malignant hypertension and in tissues that have undergone infarction or torsion. The peculiar nuclear distortions noted in the lungs have also been seen in all these other diseases. As it seem clear that an identical histological picture can be produced in these different diseases, granted that the main brunt may fall on vessels of different calibre in the different diseases, we can now regard the changes in the pulmonary arteries as a form of fibrinous vasculosis.

Fibrinous vasculosis would seem to be the result either of abnormal permeability as in the static and hyperergic types or of abnormal pressure as in the hypertensive type. If one of these precursor states is known to exist in any given case we ought surely to relate the fibrinous vasculosis to that state, and thus in these cases of mitral stenosis I believe it is proper to attribute the change to hypertension. In the pulmonary circulation therefore we are left with the same problem as faces us in the systemic circulation. What is the extra turn of the screw that in a few cases pushes up the pressure, forces fibrinogen into the vessel walls, and changes the relatively benign into frankly malignant hypertension?

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I am glad to acknowledge material for study from a group of generous colleagues so numerous that they must unfortunately be nameless here.

Pulmonary Function In The Newborn Lamb

G. S. DAWES (The Nuffield Institute for Medical Research, University of Oxford)

The investigation of pulmonary function in the newborn baby is very difficult, not least on ethical grounds, and there is therefore good reason for studying the newborn lamb. While the most that this can contribute is to define some of the factors which may determine survival in the baby, it is interesting that these should include the beneficial effect of a patent ductus arteriosus in the presence of pulmonary arteriovenous shunts, a phenomenon which has been so successfully exploited by modern thoracic surgeons.

In the mature fœtal lamb the carotid arterial O_2 saturation is normally about 60%; it falls precipitously when the umbilical cord is tied, and, as the lamb begins to breathe, rises slowly to 90% over a period which is sometimes as long as several hours. In the fœtus the lung uses about 10% of the oxygen uptake of the whole lamb, so that the blood in the pulmonary veins contains less O_2 than that in the pulmonary arteries. Any part of the lung in the newborn lamb which is not expanded therefore will not merely act as an **intrapulmonary arteriovenous shunt** but may actually abstract O_2 from the blood passing through it.

When a fœtal lung is ventilated for the first time its vascular conductance is increased and more blood flows through it at a lower pressure. This increase in pulmonary blood flow after birth causes a rise in left atrial pressure and hence assists in the permanent closure of the valve of the foramen ovale. There is another factor which operates in the same way. Before birth about 60% of the combined output of both ventricles flows through the placenta and thence up the inferior vena cava. Consequently when the umbilical cord is tied and placental blood flow ceases there is a considerable fall in pressure in the vena cava; this alone is sometimes sufficient to reverse the pressure gradient across the foramen ovale. Nevertheless in many lambs for a short time after birth blood may continue to flow through the foramen ovale constituting a **pulmonary arteriovenous shunt outside the lungs**.

The deleterious effects of these two types of pulmonary arteriovenous shunt is to some extent offset by the continued patency of the ductus arteriosus. In the newborn lamb more than half the total pulmonary blood flow may pass from the aorta through the partly constricted ductus shortly after delivery giving rise to a murmur and thrill in the pulmonary trunk. If the ductus is occluded the pulmonary arterial pressure falls, aortic pressure rises and there is a reduction in the % O_2 saturation of the systemic arterial blood (Fig 1). Experiment on adult dogs have shown that the beneficial effect of a patent ductus arteriosus can be explained by and quantitatively predicted from the consequent increase in pulmonary blood flow whether the pulmonary arteriovenous shunt is outside the lungs (as in the tetralogy of Fallot) or within their substance.

In lambs the ductus arteriosus normally constricts within 15 minutes of beginning ventilation though it is not functionally closed for many hours. A major factor in determining this constriction is the pO_2 of the systemic arterial blood (Fig 2). A fall in pO_2 causes dilation of the ductus and a rise causes constriction either in the fœtal or newborn lamb or in an isolated heart ductus preparation. This phenomenon has been observed in the absence of the lungs and central nervous system and independently of changes in blood pressure. Profound anoxæmia sometimes also causes the ductus to constrict temporarily. This is probably due to liberation of sympathetic amines since the effect can be imitated by infusion of adrenaline or noradrenaline into the fœtus.

While these circumstances may promote survival in well ventilated lambs in underventilated lambs systemic arterial pressure rises and yet does not exceed pulmonary arterial pressure. The physical conditions which limit inflation of the lungs are therefore of great interest. The pressure required to inflate fœtal lungs is considerable 30 or more mm Hg and mature lambs can produce intrapleural pressures as low as -50 mm Hg. In mature lambs positive pressure ventilation causes an initial rapid increase in distensibility (tidal air/tracheal pressure) followed by a slower increase over many hours. The lungs of premature lambs are much less distensible (per kg body weight) than those of mature lambs and the failure to obtain a sufficient increase in pulmonary blood flow on ventilation is probably the ultimate limitation to viability.

It will be apparent from this brief account that there is ample room for more detailed investigations of pulmonary function in the newborn. Yet before the elegant and ingenious methods of human physiologists can be fully applied it may well be necessary to understand the vagaries of the circulation in the human baby in more detail than is yet available.

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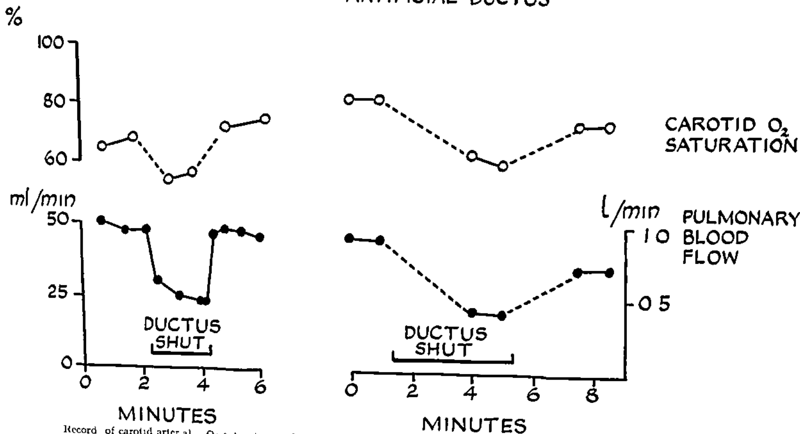
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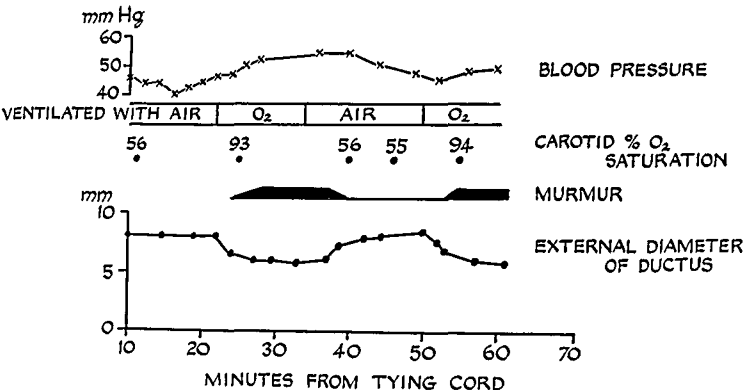
I am most grateful to my colleagues Joan Mott J G Widdicombe G V R Born and Barbara Rennick who have collaborated in this work

F gure 1



Record of carotid arter al O_2 s turation and of pulmonary blood flo in a matu e lamb del ed by cæ ar n ect on (flo meter in left pulmonary a tery) nd in n adult dog (flo v by direct Fick princ ple) pentol bitone anæsthesia In the dog an intrapulm ona y ter ovenous shunt was cr at d by br nchial ob truction and the left subcla ian art y as jo ned to the pulmona y trunk to form an art ficial ductus arterio u Clo ure of th d ctu c u s a f ll in c rotid O_2 saturation

F gu e 2



Mature l n t deli er d by c s rian ection pentobarbitone anaesthe ia Pos t e pre ure ventilat on with O_2 causes an increase n carotid O_2 saturat on nd on triction of the ductu art riosus (e ternal di meter me sured with calipers) with the appearance of a murmur in the pulmonary trunk

Respiratory Function Estimation For The Physician

W MELVILLE ARNOTT (Department of Medicine University of Birmingham)

The quantitative assessment of respiratory function by the clinician until some 15 years ago scarcely went beyond the measurement of respiratory rate and of vital capacity Since then there has been a rapid accumulation of precise quantitative data *from the newer methods of* clinical measurement and it has become possible for the physician to think in terms of the underlying mechanisms

The function of the lungs has been defined by K W Donald (1953) as the maintenance in the arterial blood of normal and nearly constant oxygen and carbon dioxide content and tensions under all physiological conditions and doing so without causing any undue sensation of ventilatory discomfort or any adverse effects on the heart or other organ Dornhorst (1952) in an analytical assessment of respiratory function regard the respiratory system as a supply channel whose activity can be characterised by its conductance which is the function relating the rate of passage through it to the pressure difference between its ends This channel transmits oxygen inwards at rates varying from 150 to 1500 ml/min and transmits carbon dioxide outwards in approximately the same volumes It is a marvel of integration that gases so dissimilar in concentration diffusibility and in mechanism of chemical transport in the blood stream should pass so smoothly and efficiently in opposite directions along this channel

From the point of view of clinical testing this channel is divisible into three zones (1) the passage from the mouth to the alveoli flow *along which can be regarded as ventilatory* function (2) the mechanisms of diffusion from the alveolar gas phase through the alveolar wall into the capillary blood stream—or **diffusion** function and (3) the hæmodynamics of pulmonary capillary *blood flow or circulatory* function

In these three divisions of respiratory function particularly the ventilatory it is easy almost fatally easy to find measurable characteristics and to amass figures Objectives must be kept clearly in view Physiological procedures may aid the clinician either as diagnostic aids or as a means of assessing severity when the diagnosis is not in doubt Again quoting from Dornhorst (1952) the justification of a diagnostic test is statistical depending on whether on the average it improves classification *of patients to an extent* commensurate with the effort it entails

I propose to outline briefly with their clinical significance the more important tests of respiratory function leaving those concerned with gas diffusion — across the alveolo capillary membrane—to Dr Bates who has been deeply engaged in this aspect

Ventilatory Function

The measurement of the static lung volumes has been extensively practised and has shed a certain amount of light on lung disease The residual volume is usually measured in this country by *the closed circuit helium dilution* method of McMichael (1939) as modified by Meneely and Kaltreider (1941) and in the U S A by the open circuit nitrogen wash out method of Darling Cournand and Richards (1940) *Normally the functional residual capacity* is about half of the total lung volume and the residual volume varies from 20 to 40 of the total lung volume Higher values are found in older people It must be emphasised that it is *quite likely that values somewhat in excess of* 40 may be found in a few healthy people so that diagnostic reliance must not be placed on this test alone Many of the departures from normal are clearly related to obvious structural *change and do little to illuminate the situation* For instance in massive consolidation lung collapse without air trapping partial or complete pneumonectomy &c the total lung volume and in proportion its subdivisions are reduced The *characteristic of emphysema* is a normal or slightly increased total lung volume with a disproportionate increase in residual volume resulting in a residual/total lung volume ratio of above 0 5 However the relationship of this increase to *the degree of disability* as assessed by the arterial blood desaturation at rest and with exercise by the amount of carbon dioxide retention or by the extent of pulmonary hypertension is inconstant (Baldwin et al 1949)

The syndrome of pulmonary fibrosis due to a wide variety of pathological processes has the obvious effect of restricting pulmonary distensibility consequently reducing the total lung volume and the inspiratory reserve volume with*out altering the other* absolute measurements the result is reduction in vital capacity and increase of the residual/total lung volume ratio

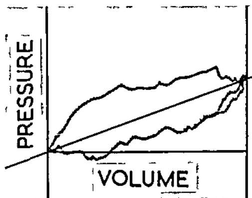
Both the open and closed circuit methods of measuring functional residual capacity provide opportunities for measuring the rate of gas mixing The abnormally high concentration of alveolar nitrogen after seven minutes quiet breathing of oxygen and the unusually long time taken to achieve closed circuit equilibrium in respect of helium both in emphysematous patients illustrate the gross inadequacy of alveolar ventilation in that disease

Lung volumes of course are pure statics A dynamic test which embraces rate of volume change is the Maximum Breathing (or Ventilatory) Capacity in which is measured the amount of air breathed in any given time which may be as long as 15 or as short as 1 sec The result is expressed in litres/min At first the test was often done by urging the patient to breathe as hard as possible leaving the patient free to choose his own frequency and amplitude Nowadays it is more usual to control the rate at frequencies of 50 60 and 70 The work of Bernstein d Silva and Mendel (1952) in designing a spirometer capable of responding accurately to these high frequency phase reversals has greatly improved the value of the test As the ordinary Benedict spirometer is virtually useless for this purpose the only alternative method is the collection of expired air in a Tissot spirometer or a Douglas bag In assessing the value of this test Donald (1953) has emphasised that although it is a useful measure of the pumping capacity of the chest many attributes of this activity are being tested simultaneously Furthermore there is this element of unreality about it that the amount of air that can be breathed is in the healthy about twice the amount ventilated by a normal person subjected to the most powerful physiological stimulus This test remains the best overall yardstick of ventilatory insufficiency without any great capacity to differentiate the nature of the fault

Much work has been done on the cost of ventilation in terms of ventilatory volume per unit of work and in relation to the maximum ventilatory volume This will gain in value to the clinician as normal standards in respect of age sex &c emerge

There has recently been a revival of interest in a method of studying the work of breathing devised some 30 years ago by v Neergaard and Wirz (1927) mainly by Otis Fenn and Rahn (1950) in America and Christie Marshall and McIlroy (1954) in this country This consists of the application to the bellows action of the lungs of the principles the engineer employs in studying the physics of pumps and heat engines The central point is the construction of a pressure volume (P V loop) diagram of air pressure and volume in the lungs throughout a respiratory cycle (Fig 1) The major axis joining the points on the loop corresponding to no-flow at the height of inspiration and the depth of expiration forms the hypotenuse of a triangle whose area is proportional to the work done in overcoming the elastic recoil of the lungs while the area enclosed by the major axis and one boundary of the ellipsoid is proportional to the work done in overcoming the viscous and turbulent resistance to air flow and the viscous resistance to deformation of lung tissue Already this technique has shed much light on the mechanics of breathing in respect of the physiological factors governing the relationship between frequency and amplitude of breathing in the setting of the resting respiratory level and in the distorted mechanics of lungs stiffened by disease and air passages narrowed by thickening and spasm of their walls At present it is a research procedure but it is quite likely there may evolve from it comparatively simple tests applicable to routine clinical practice

Figure 1



The loop of intra-œsphageal pressure and tidal volume (Arnott W M Butler J and Hancock A C 1954)

Circulatory Function

The most useful blood test of respiratory function open to the ordinary clinician is the estimation of the oxygen and carbon dioxide contents of a sample of arterial blood withdrawn preferably from the brachial artery The routine practice of this procedure has revealed how severe may be the arterial unsaturation in many forms of respiratory disease A glance at the dissociation curve of hæmoglobin reminds us that a reduction of only a few per cent in oxygen saturation represents a gross depression

of oxygen tension This test can be made much more revealing if performed immediately after exercise (always supposing the patient be capable of this) because often enough ventilatory function is sufficient to maintain normal arterial saturation at rest but quite inadequate to cope with increased oxygen uptake Any defect such as emphysema which seriously impairs alveolar ventilation raises the carbon dioxide content of the blood The importance of this factor in the production of the carbon dioxide narcosis sometimes seen in severe cases of emphysema treated by oxygen inhalation was pointed out by K W Donald in 1949 and has since received much attention notably by Westlake Simpson and Kaye (1955)

In conclusion I would emphasise that brevity has resulted in a very sketchy survey (not including bronchospirometry) of this subject and that the most important subject of gas diffusion and ventilation perfusion relationships is left in the safe hands of Dr Bates

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Gas Diffusion And Lung Function

D V BATES (Dunn Laboratories St Bartholomew s Hospital London E C 1)

The study of the process of gas diffusion in the lung illustrates the universal difficulty of applying simple physical laws to the field of biological investigation The characteristics of a membrane (A) in terms of diffusion through it of a substance (X) may be defined as follows —

$$\text{Diffusing capacity (cc/min/mm Hg)} = \frac{\text{ml/min of X transferring A}}{\text{Gradient of pressure of X across A}}$$

Gas diffusion is of physiological importance in the human lung since oxygen has to pass by diffusion from alveolar gas to red cell hæmoglobin We may recognise at once several factors intimately concerned with the speed at which this process can occur an obvious one being the *permeability* to oxygen of all the structures that separate the gas from hæmoglobin Since oxygen must pass into hæmoglobin the rate of transfer as it will be measured is in addition affected by the surface area of hæmoglobin exposed continuously to the gas and by the kinetics of the reaction between O_2 and Hb

The methods that have been devised to measure the pulmonary diffusing capacity for oxygen are complex and limited space precludes any detailed discussion of them The evident difficulties in calculating the oxygen pressure across the alveolus have been brilliantly surmounted by Lilienthal and Riley but the method remains a formidable technical procedure Ever since the pioneer work of the Kroghs in 1910 the use of carbon monoxide for the investigation of pulmonary diffusion has seemed the method of choice and this technique *has been simplified by the introduction recently* of physical methods of gas analysis applicable to carbon monoxide The rate of diffusion of CO from the lungs (Dco) may be measured either by a single breath or by a steady state method Each of these possesses advantages and disadvantages in practice but so far all available evidence suggests that the two methods give results of the same order of magnitude

What has been learnt so far of the nature of gas diffusion in the lung? In summary the following points have been established —

1—The normal resting diffusing capacity is about 21 cc/min/mm *Hg for oxygen* and about 17 for CO

2—The diffusing capacity increases by about 75% on exercise and usually reaches its maximum well before the limit of effort or of oxygen uptake has been reached

3—The diffusing capacity is greater as one would expect in persons with a large lung volume

4—Increasing age reduces the diffusing capacity

5—There is evidence that the ratio between contained gas volume and the rate of diffusion is not constant within a normal lung

6—It has been realised that the measured overall rate of diffusion will be dependent on the ratio between ventilation and diffusion in different parts of the lung

7—Gross disturbances of gas diffusion have been demonstrated in disease sufficiently great to affect overall lung function

We come now to a major difficulty In many respiratory diseases we know that there is a gross abnormality of gas distribution within the lungs and we may assume that there are in addition wide variations in gas diffusion in different parts In cases where the lung has departed so widely from being an ideal single alveolus what meaning can be attached to an overall measurement *of a single figure of gas diffusion? This problem* is still far from solution and until this aspect of the measurement is better understood the interpretation of some of the results will remain a matter of opinion

Figure 1 indicates some of the mechanisms which may be responsible for impaired overall gas diffusion The examples quoted are intended to be illustrative and do not constitute a comprehensive list It is clear that impaired diffusion as revealed by current techniques may be caused in a number of different ways and further that in a condition such as mitral stenosis—in which impaired overall diffusion may be demonstrated—alveolar wall change inequality of gas distribution and inability to increase the cardiac output may all contribute to impaired gas transfer The number of question marks on this figure illustrates the tentative nature of some of the conclusions that may be drawn

Impairment of gas diffusion if of sufficient severity may show itself in a number of different ways —

1—By causing excessive ventilation for a given oxygen uptake the ventilation being required to keep the alveolar oxygen tension as high as possible

2—By causing arterial unsaturation on exercise the muscular weakness that follows may limit effort tolerance

3—If grossly reduced by limiting the maximum oxygen uptake to a very low figure In emphysema this may force the patient into the dilemma that the increased amount of oxygen that would be transferred if ventilation were increased is more than offset by the increased oxygen needed to achieve that ventilation

Finally how useful is this measurement in physiological study and clinical research? Physiologically the method is of most value in giving information about the nature of the pulmonary capillary bed In 1945 Prof Roughton in a remarkable and ingenious contribution used the kinetic equation for the rate *of formation of COHb at different oxygen* tensions to calculate the pulmonary capillary blood volume quantitatively No one as yet has followed up this lead but there is every indication that the next few years will see a considerable advance in this aspect of respiratory physiology It is also rather surprising that gas diffusion has not been more studied in experimental pulmonary oedema

In clinical research and investigation one may single out three examples to illustrate the value of this type of study

1—In pulmonary emphysema the overall diffusing capacity gives an indication of the state of the lung parenchyma This information is not obtained from any of the ventilatory tests and it constitutes an essential part in the assessment of any patient who might have some degree of emphysema The discrimination achieved by the measured diffusing capacity on exercise when young normal subjects are compared to cases of emphysema is shown in Fig 2 Ventilatory tests of course show similar differences but there is good evidence that the two groups of tests are concerned *with quite different* aspects of function change

2—It is of particular use in the study of the occasional cases of obscure pulmonary infiltration that are met with in which the impairment of gas diffusion will forecast the alveolar wall changes that the pathologist will demonstrate and that the radiologist may have difficulty in showing

3—It may be used in the study of cardio pulmonary phenomena such as left ventricular failure with pulmonary congestion This condition may produce impaired gas transfer and changes in pulmonary diffusing capacity may be sensitive indicators of change

I hope this bird's eye view of an active field of respiratory physiology will serve as a basis for discussion

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Figure 1

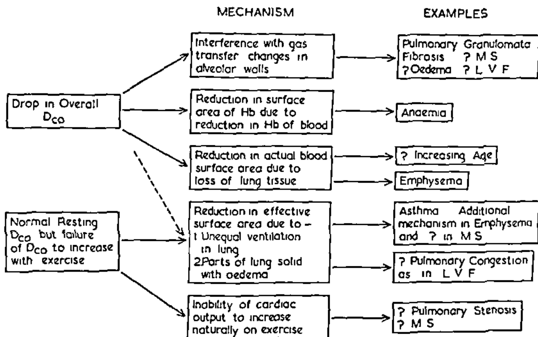
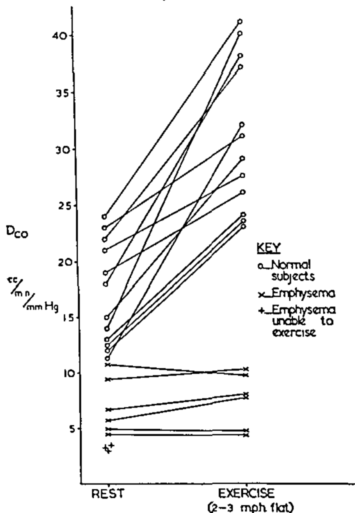


Diagram of some of the mechanisms of production of impaired overall gas diffusion Abbreviations—Dco=CO Diffusing capacity M S =Mitral stenosis L V F =Left ventricular failure

F gu e 2



Comp r son betw n th d ffu ing c p ity of no m l ubj ct d p t nt w th emphysem t rest nd o n il l exercise Th g r nge of tl norm l subject wa 18 to 4 Tl g os imp rm nt in mphysem i principally aused b y th l struct on of lung p renchym present th con l t on

Breathing Machines And Assisted Respiration

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The development of mechanical breathing apparatus has greatly expanded therapeutic application of assisted or artificial respiration As long as manual methods alone were available artificial respiration was only used in the treatment of emergencies such as drowning anæsthetic failures or exposure to toxic gases where treatment was only required over minutes or hours The introduction of the tank respirator by Drinker in 1929 opened the way to the development of mechanical methods suitable for chronic cases requiring respiratory assistance over weeks *months or even indefinitely* The potentialities of this form of treatment are in fact only just coming to be realised Some of the conditions in which respirators have been used in addition to their use in acute emergencies are —

TABLE 1

NEUROLOGICAL — Poliomyelitis Peripheral neuritis Myasthenia gravis Tetanus

POISONING—*Barbiturates Alcohol*

PULMONARY—Emphysema Acute respiratory infections in patients with grossly reduced lung capacity

SURGICAL—Thoracic surgery Head injury

PEDIATRIC—Respiratory difficulty in newborn and premature infant

My purpose here is however not to discuss treatment of respiratory failure in these conditions but to describe the main types of respiratory or breathing machine and their uses

A bewildering number of different machines has been designed but they fall into the following categories —

TABLE 2

TOTAL VENTILATION — Tank respirator (Drinker Both etc) Positive pressure breathing machines Volume cycled (*Engstrom Power etc) Pressure cycled* (Aga Pulmotor etc) Patient cycled (Bennett etc)

PARTIAL VENTILATION—Cuirasses Rocking beds Pressure belts

TANK RESPIRATORS — These are sometimes called negative pressure machines because they act by reducing the atmospheric pressure outside the body Their effect however as far as the pressure differences across the lungs are concerned is the same as with so-called positive pressure breathing A tank respirator consists essentially of a coffin like box with an aperture for the neck and a sponge rubber or plastic neck seal *The* patient is ventilated by rhythmically lowering the tank pressure by 12 20 cms of water by means of a large bellows Expiration is usually allowed to occur passively though in some respirators positive pressure can be applied to assist expiration Modern developments in tank respirator design are mainly concerned with improving facilities for getting at the patient for nursing purposes and for ventilating the patient by *positive pressure when the tank is opened or* the patient removed from it as the case may be

Some 900 tank respirators are available in this country and are distributed among fever hospitals and general hospitals They form the reserve of mechanical respirators available for handling a poliomyelitis epidemic

POSITIVE PRESSURE BREATHING MACHINES—These are classified according to the method of controlling the breathing cycle

A **volume cycled machine** delivers a standard volume of air independently of pressure though it may be fitted with a blow-off valve to guard against dangerously high pressure being applied *to the patient Examples of this type of machine* are the Beaver respirator made by the British Oxygen Company and the Swedish Engstrom respirator

Volume-cycled machines are operated either by a piston pump in which case provision has to be made to prevent contamination of the inspired air with oil vapour or by a bellows The form of the pressure curve is determined by the shape of the cam which operates the bellows or cylinder

The stroke volume and frequency are adjustable and in the more complicated machines like the Engstrom respirator the wave form can also be adjusted In Denmark and Sweden where *large scale epidemics of poliomyelitis* have occurred this type of apparatus is preferred for treating the more serious cases of respiratory insufficiency in poliomyelitis

A **Pressure cycled Machine** pumps air into the patient until the pressure at a given *point in the* system (preferably near the mouth or trachea) rises to a set value whereupon a valve shuts off the air flow from the patient and the patient exhale passively to atmosphere The best types of machine have magnetic valves in *which the*

cycling pressure overcomes the pull of a magnet These are more reliable than those which depend on breaking electrical circuits by movement of fluid or mercury in response to pressure In pressure cycled machines a continuous gas flow can be used since the flow is merely diverted during expiration and not shut off Cheap and compact machines are available using compressed air or oxygen or a vacuum cleaner blower

This type of machine is very suitable for transport of acute poliomyelitis cases in ambulances or for other respiratory emergencies It is also favoured by Scandinavian physicians for treatment of chronic poliomyelitis cases because it is relatively simple and cheap and the patients like it It is contra indicated in their view for acute cases

1—Because if obstruction develops in the air way due to secretions etc the machine can go on cycling without delivering its quota of air

2—Because if a leak develops between the patient and the machine the machine may cease to cycle altogether

Patient Cycled Machines—These machines tend to be more complex than other types because of the need to respond to small changes of pressure set up by the patient s natural respiratory effort Some depend on mechanically switching others have electronic devices They are used commonly in the treatment of respira tory embarrassment without muscular paralysis for example in emphysema particularly in association with atomisers for administering bronchodilator drugs They have not yet found wide application in poliomyelitis

Common to all positive pressure machines is the need for a gas tight air way and since positive breathing masks can only be used over short period their use over prolonged periods is limited to tracheotomy cases In Denmark and Sweden it is common practice to keep tracheo tomies open for months and sometimes years

Cuirass Respirators—There have been many attempts to make cuirass respirators beginning as long ago as 1901 Even the most successful ones have not been efficient enough to keep severe cases of respiratory insufficiency alive and patients have died with pulmonary oedema from under ventilation By the 1930 s models were available which were adequate for convalescent cases One of the first was the I C C Burstall jacket which was like a suit of armour encasin the whole of the trunk Subsequent develop ment particularly since the war have been towards greater ease of application combined with greater efficiency Ease of application depend on having the minimum amount of fixing behind the back Respiratory efficiency depends on the amount of trunk included minimum restriction to rib movement both anteriorly and laterally and maximum diaphragmatic movement The cuirass should seal behind the mid axillary line below the epigastrium (i e over the hypogastrium) and as high as possible on the sternum The seals them selves should be very thick and soft to allow a certain amount of movement underneath Such respirators belong to the chest abdominal type as opposed to the less efficient chest type Chest cuirasses tended to move the anterior part of the che t only Chest abdominal types aim at moving principally the diaphragm and lower ribs The most recent one in this country is the Spira Shell developed by Dr Kinnier Wilson and his colleagues and manufactured by the Medical Supply Association It is claimed to give 25 per cent greater tidal volume for a given negative pressure than the well known Monaghan type the most recent model of which is also of the chest abdominal type The greater efficiency of the Spira Shell is due to the fact that it widens on suction whereas the Monaghan compresses laterally on suction

Cuirasses are not suitable for acute cases for the following reasons—They may not give adequate ventilation sealing is not completely reliable and posturing the patient for drainage is difficult

Rocking Beds—These are now coming into use in this country having been used for some years in the U S A Some patients prefer them to cuirasses and can sleep on them They can be relied on to supply about 60 per cent of the total ventilation Their main advantage i that the patient is completely unencumbered The angle of tilt is usually 30 35 degrees (15 degrees head down and 15 degrees feet down)

Pressure Belts—These compress the chest during expiration Inspiration takes place by elastic recoil or by the patient s own in piratory effort They are nowadays seldom used though they are good for convalescent patients who cannot leep to give the extra 100 cc of tidal volume

Electrophrenic Respirators (Sarnoff)—These have little place in poliomyelitis It is considered undesirable to stimulate affected muscle more over the nerve may eventually cease to conduct It is also difficult to find the motor point and to keep the electrode on it They may however be of value in patients with disordered action of the medullary centres who are difficult to treat in other respirators since they seem to inhibit the natural in piratory effort

Three important accessories used with breathing machines will now be considered

Spirometers—An important requirement in the practical use of any type of breathing machine is a spirometer since it is important to know the minute volume of ventilation and this cannot be determined accurately from the pressure changes Some positive pressure breathing machines notably the Engstrom have a built in spirometer failing this a small gasmeter type spirometer is suitable

Suction Apparatus—Some form of suction must be available for aspirating secretions from the respiratory tract This can be done either by means of a separate aspirator pump or by a venturi tube incorporated in the breathing *machine*

Humidifiers—In patients with tracheotomies it is important to prevent formation of crusts in the respiratory passages due to inhalation of dry air *It will be recalled that inspired air is* normally saturated and at body temperature by the time it reaches the trachea Many otherwise satisfactory breathing machines are deficient in this respect Either they have no humidifier or the humidifier is too small to be effective or placed too far from the patient so that the inspired air cools by the time it reaches the patient and drops most of its moisture by condensation

I hould like to close with a few remarks on the treatment of respiratory poliomyelitis Any one visiting Denmark and Sweden is likely to return firmly convinced that tank respirators are out of date and that a volume cycled positive pressure machine is necessary for adequately controlled treatment in severe cases of acute *respiratory poliomyelitis and that a pressure* cycled machine is the equipment of choice for the chronic case This view is based on the Scandinavian experience that 70 per cent of respiratory polio cases require tracheotomy at some stage and problems of nursing and medical care are much simplified by use of positive apparatus rather than with tank respirators At Danish and Swedish centres tracheotomies are kept open for long periods in order to allow this method to be used

In the U S A on the other hand when comparable epidemics have occurred tank respirators are considered superior The mortality at one centre which I visited was stated to be as low as 12 per cent compared with 25 30 per cent in Scandinavia Tracheotomies are allowed to close early as soon as the patient recovers the power of swallowing In the chronic phase wide use is made of rocking beds and cuirasses

The difference between the two methods has grown up largely on the basis of the equipment which the different countries had available at the time when they began to have serious epidemics Centres in the U S A and Canada *were already equipped with tank respirators* Denmark and Sweden had little equipment of any kind They used manual positive pressure techniques in *the* emergency *conditions of the* early stages of their epidemics and later developed some very efficient types of positive pressure breathing apparatus

In this country we are in the same position as the U S A consequently it is unlikely that positive pressure breathing will be adopted on a wide scale for treatment of respiratory poliomyelitis *Positive pressure breathing has* however a wide field of application in the other conditions listed above It seems likely from a study of mortality rates both in Scandinavia and the U S A that skilful clinical management backed by adequate laboratory facilities are more important in reducing mortality than the actual type of respirator

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Augmented Respiration With Patient-Cycled Respirators

IAN DONALD (Department of Midwifery University of Glasgow)

The need for an apparatus that would amplify respiratory efforts however feeble or irregular became obvious some years ago in the course of our experiments in treating respiratory *difficulties in the newborn* particularly premature infants It had been found that an infant Drinker type of apparatus although having a wide *range of speeds* of operation and pressures failed to produce any noticeable benefit because the baby fought the rhythm of the machine with its own spontaneous respiratory efforts if strong enough to do so and treatment along these lines more often than not hindered rather than helped it

Respirators have therefore been developed which are operated by a servo-mechanism which is triggered by the onset of each inspiratory attempt. Such a respirator being patient cycled adjusts itself to the needs of the patient in so far as the respiratory centre is functionally competent and moreover the hypothetical possibility of hyperventilation is less likely.

Two main types of respirator have been used and are undergoing further development although both operate on the same triggering principle. In the first of these, namely the servo-respirator, the baby is enclosed in a miniature type of cabinet respirator in which negative pressures are applied to the body synchronously with the inspiratory phase. The neck and face are sealed from the body chamber by a setting solution of calcium alginate. In the other type, namely the Pneumotron, inspiration is assisted by intermittent positive pressure applied either by a face mask or by an endotracheal tube. This provides a short term emergency type of treatment in the hands of unskilled personnel. Positive pressures applied by a face mask without regard to the timing of the child's respiratory efforts tend merely to drive the administered gases down the œsophagus into the stomach, whereas if such a pressure synchronises with the natural inspiratory phase of the patient during diaphragmatic systole the pulmonary intake is more likely to be increased.

The triggering mechanism is controlled by a flap inspiratory valve which is mirrored. A light reflected from this mirrored surface on to a Germanium crystal is deflected at the beginning of each inspiratory phase and the output from the Germanium is sufficient to operate a sensitive relay. The relay controls two standard Elcontrol timing units, the first of which provides the "hold in" time to determine the duration of the positive pressure. The second provides an automatic cycling time which causes the apparatus to work at any given frequency if spontaneous respiration should cease and therefore fail to trigger the machine. Both circuits provide a wide range of settings. The output relays from these timing circuits are connected in parallel to a powerful solenoid which opens a piston valve. A positive pressure of approximately 4 lbs. per square inch, reduced in two stages from a standard gas cylinder, is constantly applied to the piston valve. This system eliminates time lag between triggering and operation. Any gas mixture can be supplied and our preference is for a 50/50 oxygen and nitrogen mixture supplied from one cylinder.

The pressures delivered to the patient cannot exceed 30 to 35 cm. of water because of a weight operated blow-off valve. A regulator valve in the delivery system can adjust the rate of pressure rise within the mask.

In the event of apnœa the automatic timing circuit assumes control and continues to trigger the apparatus at any desired frequency until the next spontaneous inspiration triggers the next cycle of operation.

The efficacy of this principle of treatment is being studied by intraœsophageal electromanometry along the lines of Dornhorst & Leathart (1952) and the pressure changes thus demonstrated within the thoracic cavity can be studied and compared with the pressures occurring in both natural breathing and other methods of artificial respiration. In the case of the servo-respirator, the pressure effects of augmented respiration and spontaneous inspiratory effort have already been shown to be additive (Donald 1954). With the positive-pressure Pneumotron the pressure waves are of course reversed and the degree to which this reversal takes place gives some indication of the adequacy of the gas flow delivered by the apparatus.

The Pneumotron has been designed also to provide augmented respiration in adults and experiments on curarized patients undergoing operation are being conducted and the effects studied by intraœsophageal manometry. As spontaneous respiration returns the Germanium cell trigger takes over from the automatic timing circuit.

The apparatus has not so far been used in cases of respiratory paralysis, complete or partial, due to disease. Its value in such cases has not only to be established by objective measurements as above but has to be weighed against a certain degree of electronic complexity. Nevertheless the use of a Germanium crystal in place of the former gas filled photoelectric cell and D.C. amplifier together with standard timing units has already simplified the apparatus and made it more reliable than its prototype.

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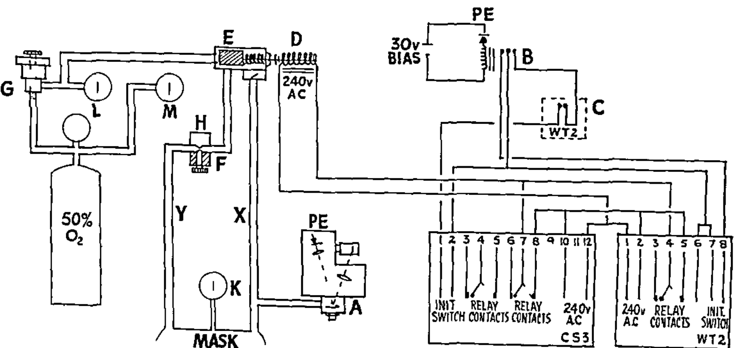
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This research has hitherto been made possible by a Leverhulme Research Scholarship awarded by the Royal College of Obstetricians & Gynæcologists and is now being further supported by the Scottish Hospital Endowment Trust. Grateful acknowledgment is also made for assistance provided by Dr. Lenihan and his staff of the Physics Department of the Western Regional Hospital Board.



A	Inspiratory Mirror Flap Valve
PE	Germanium Junction Photo Electric Cell
B	Trigger Relay
C	Break Contacts to isolate CS 3
WT 2	Hold on Timer (Inspiratory)
CS 3	Cycling Timer (Automatic)
D	Mains Operated Solenoid
E	Piston Valve

F	Volume Control Valve
G	Pressure Reduction Valve
H	Blow off Valve
K	Mask Pressure Gauge
L	Pressure Reduction Gauge
M	Cylinder Pressure Gauge
X	Exhaust Pipe
Y	Delivery Pipe

DISCUSSION

Dr C M FLETCHER

The great progress that we h t made du ng th l t 10 year in our underst nding of lung fun t on may be een by comp ri g a recent book such a th t by Comroe and his olleagues (1955) with ch t ters on re p tion n books of cl n cal physiology p bl hed 10 ye ago De p te th s progress the v rous techn que de loped for lung functi n stud re seldom used n cl n cal wo k in this country o t de a few research units in wh ch they have b en an l are be n d l ped Is th fact a reflection on th t ck wardness or conserv t m of clin cian o t due t the c mple ty of th t chn qu o t th i l ce to cl n c l pr ct ?

Relevan of Lung Funct on T t to Cl n cal Pract e

In th great majority of c ses of che t d sea e th cl n cian ad olog st and patho log st c n pro de n accurat atom cal nd p tl olo l d gnosi pon wh h prog osis and t eatment n be securely b sed F cti n t ts can only p ide dd t onal fo mat on n cases who have m d sturb c of p r to y function usually man f ted b y dy pnoe or y nos Ap rt f m the undo bt d ntellectual t m lu prov ded by th se tests th dd t on l in f rm t n ften of pr t c l use to the clinician or his patient

In case w th dy pnoea fu ction t t m y h lp n tw m n w ys—

( ) M asurement of the sev rity of dy pnoea

Cl n ian ally stimat dy pnoe w th as ur nce but t des t the rep t bility of u h e t matt g l ttl co fiden n th ccuracy A w th oth l m l m thod an ol j cti e t t should upplem nt bj ti e t mat Th e pec al n ed for quan t t ti ol ject mea ement of dy pnoea ng at lity fo w k d sab lity for I dustr al Injury B fit fo d st gu l in between the ubject e and objecti e effects of t tment d in asse n u tab l ty f r tho acic surgery

H w n dy p b me u ed It m l sensat on of ff rt n b th g gre t than that normally f lt at y g ven l l nf activity Ch t (1954) ha usef lly ompared the act ty of breath ng t th t f w lk g—both are hythm al t v t carr d out without c nsc ou ff rt

I both ensation f str n or effort ar e tt wh n the t vity s in r ased (g g uphill n walki g in rea g entil t on n breathing) or wh n th cap c ty to p rfo m educ d (we kn s o stiffnes n walk ng educt on n vent l tory capac ty n t re th g) An ind f dysp oea may th re so t ly be ba d pon m urem nts of th two f to Th fi t can be m u d th ol m of air b e th d out t y th p tent wh n he perform st nd rd se th co d t y m a u ng th lum wh n l b eath a h d as h an f r m as d per od Var o m th ds fo m suring nd el t g th se tw a at l are a la le Th e w th whi h I h e had most per n s that d sed by H gh Jon (1952) The se ty of th e se i st nda d sed so that th patient lways do the am am t of exte n l wo k d pite ari tions n the e ght In ord to allow f r ors nt o d c d l y p tie ts f li g to compl te the st nd d p od of e rcise or fa l g to h ev a st ady t t of exerc vent l t on the total e ess vent l t on (above the re ting level) is aver ged over the ctual duration of e ercise In oth r te ts the lack of such tandardi ation ha led to conf on in interpretat on of exerc se ventilation and to d sat faction with the ind x

The dy pnoeic ind x derived from this test (xer cise entilation as a prop tion of maximum vent la t on) correlates well on the erage with cl n cal a se ments of dyspnoea l ut there s a wide sc tter of ind e with n e ch clin cal group Thi w d atter m ht g t that th nd is a poor o but I beli ve that th atter i due more to the inaccu cy of th ul jective than of the object ve ind In no m l ubj ct t has been shown that the inde on t nt from day to day so th t en f t cannot be used unreservedly for absol te me u ements of dysp oea t an be used confid ntly to assess the re ult of t tm nt o p o re on of d seas Furth r mo e the te t pro id a useful pointer to po ble causes of the dy pnoea a d a guid to th further n e tigati n

(b) I d cat n of the Cau of Dy pnoe

The simpl dy pnoea te t will show whether th dy pnoe is d to n re se l ntilatory d mand or to d mini hed nt latory cap ty o to both Th functio al disord rs l kely to b pon ble m y thu becom l r er (see Tabl) and if n cessary further m re el bo t t st m y be a ied out to identify th m

In e w th Hypoxaem a th essenti l thing is to d sco er th m Apa t f om th d ff ulty of dis t ngu sh g p ph ral from nt l y n s there t th seriou un l b lity l clini al se m nt of y no (Comroe and Bot lho 1947) The cl n n his no m e j t f ation fo th d gnosis and treat ment of hypo m a w thout labo t ry gu dan e th n h ha for th d gnos and t eatm nt of mi n ply on th b s of p llo Measurem nt of t l t lo d o y g n tur tion sent al in the d gno s of ll ases of r p tory f ilure nd m a ment of CO ten on a e s nt l both in d gnos nd m g m nt The l tt m urement p r t ula ly mpo t nt in case rec n i ted re p a t on by th t hn q s wh h hav b n d r bed to u fo th CO t n on i th mo t el abl n t of und o o r ve til t on

Compl ty of Lung F nct on T ts

Th techniqu of the te ts which I h been d ing t nly no mo ompl cated than th t ay of B M R t mat on r of m ny o t n cl n l p th l g l t t Ind d tl c e te t w th th h lp f ec nt impl f cat on u h th peak flow m t and the min tu v n a momt d el p d by W ght (1955) should be with n the ap c ty of any phys c an n th out p t nt departm nt o on ult n o m Som of the mo d t l d tests a not yet u t bl f o t n b t we mu t hope that t w ll not be l bef r they too have been mpl fi d so that th y can be d by those w th ut el l ate tra ning o lon e pe en

My conclusion are that me m nt of l n f nct n e lly e sent l fo th p per d agno s u d rst d g and manag m nt of many f n t ll c ses with fu ct on l d stu b n of th i l ng and th t at lea t the mpl t t t re with n the scope of ny l m al d p rtm nt We mu t hop that

symposia such as this may help to draw attention to the need for wider use of modern techniques

Details may be obtained from Dr B M Wright Pneumoconiosis Research Unit Llandough Hospital Penarth Glamorgan

TABLE

Increased Ventilatory Demand

1—Uneven ventilation or blood circulation (e g emphysema pneumonia collapse)
—Alveolar capillary block (e g pulmonary oedema or granulomata)
3—Right to left shunt
4—Neurosis
5—Increased sensitivity of respiratory centre (e g altitude)

Decreased Ventilatory Capacity

1—Loss of functioning lung (e g consolidation collapse resection pneumothorax)
—Pulmonary congestion (e g heart failure)
3—Pulmonary fibrosis
4—Airway obstruction by p m r udite t
5—Emphysema
6—Muscular weakness (e g poliomyelitis)
7—Rigidity of thoracic cage (e g ankylosing spondylitis)

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Dr ROBERT COOPE

It was said of a certain report that it reflects the attitude of a man who clarifies the whole course of thought by first asking those two fundamental but so often neglected questions

What do we know about this

What do we need to do about this

You have thought both these aspects worth pursuing in the Symposium and so you have invited both the wise and the prudent—the scientist wise to discern these things and the doctor who (once convinced that they are true) is skilled to apply them—or sometimes prudent not to apply them

The working physician is likely to be out of his depth when confronted with some of the more esoteric *equations* of the respiratory physiologist Nevertheless we must measure things and analyse them as accurately as we can and therefore equations there must be I myself have a particular affection for this one

Impedance Equation

(after Coffin and Wi in Z f llg Physiol Physicochem Biol u Pharm codynam Path u Med u so Weiter 1900 3004 96)

$$\text{RHPNI} = \frac{\mu I + hS t\pi - (\text{PBRB} + nr + ck)}{\beta \Delta}$$

Where RHPNI is the resistance of the humdrum physician to new ideas
- μI is mental inertia
- hS honest scepticism
- $t\pi$ thoughtfulness for the patient
- PBRB partial pressure of the backroom boys
- nr necessary receptivity
- ck cerebral compliance
- and $\beta\Delta$ the atmosphere of Bonnie Dundee

What does the working clinician get out of all this present activity?

1—The **excitement** of knowing that intensive work is being done in the respiratory field after a long gap when scientists appear not to have found any great enjoyment in tackling its problems The working doctor always has a sneaking hope that something may be produced from the conjuror s hat to make his job of delicate judgment easier and that there will emerge facts and figures which will be really more helpful to him than what are called clinical impressions

2—An appreciable though as yet limited **practical illumination** with the promise of more—for example the mechanism of CO_2 narcosis the light thrown on suboxygenation the result of uneven ventilation and so on It is true that sometimes things are being measured in detail which to the clinician are obvious in a rough but adequate way Moreover there is the occasional clinical problem which only research techniques can solve

3—The promise of a much clearer conception of the cardinal processes though speaking for myself mathematic thought will somehow have to be translated into pictures (rather as Comroe and his co workers try to do in their recent monograph) In this Symposium I certainly sense a strenuous out pouring of energy both from scientists and doctors in the attempt to see our way through the forest of facts which are now being accumulated We are all striving towards a better integrated view of our own field I would hazard a bet that this is eventually going to lead someone like Professor Arnott (for example) to link up with say Coulson s department of mathematics at Oxford to produce an electronic computor which will iron out all the variables and put them in their place and as a spectator *I am* all for it!

The physician s integration however has to be rather different for his most important and persistent variable is the ill person of whom he has to take care Moreover the art is long time is fleeting and *life is short* So inevitably the working doctor must ask questions (of himself and others) such as these—

Do your figures interesting as they are really help me to manage this sick person? Does this technique or that give us clinical results commensurate with the time (and money) spent on them in other words do they really pay their way in the sphere *of clinical medicine or surgery* or are they for the research laboratory and the occasional problem? Are they worth on balance any pain or stress or inconvenience which they may bring to our patients?

There is thus the curious situation that while the working doctor wants as much help as he can get from the scientist yet at the same time he is apt to fear the Greek bearing gifts and he suspiciously asks—must s— Is your journey really

nece sary? It sound churlish but in fact it i not really so and whenever you fall ill yourself you w ll und tand Mor over once you h ve con inced *him that th journey is nece sary you wi l get h s* full support and he can usually carry the day with th patient

4—It wo ld b a good idea if som re piratory tests were rechr tened respiratory trick That would rem nd u ll of their intention their scope d their limitations I would give maximal bre th g capacity as an e mple

As an older physician I hav been fa cinated to look back over the years and r lise that whi e we ta ght (for e mple) vital capacity partly becau e we thought phys ol gy the b s of med cine and p rtly bec use we d d not know any better in actual fact we did not rely overmuch on it I fear that we sa d one thing and did anoth r In tinctively e relied on something mo e dynam c we tested by loid asked wh t the pati nt could ctually do in runn ng o walk n or str gglin up o e or two *fl ghts of sta rs* We also ask d was he fit to do the trick? a d furthermo e was he doing h best? and yet ag n f not why not? Then as now th o-operat on of the patient was recognised s a crucial f ctor

5—If we could li e w th a pat ent for a long t me *nd obs rve h m continuou ly and lo ly we hould* h e a bett r idea of how h stood There a good d l of mere l p serv ce given to the ide of clinical h tory yet an exper enced doctor can often elicit a h tory from the pat ent which s a good equ alent of l n with hi n n the se se th t the up nd *do n of the line s* emerge v dly These are fact which may well be ven mor tal to the doctor s act of judgm nt than any figu es provid d by th re pi tory phy olog t M y I gi e you a ery mple illustration

Th p tient known for some years to h m tral *tenosis* w sent to hosp tal fo pos t le operat on The only cc nt lln of any note w n attack of infl en a two years bef re There ere no p sent ympt m of illn ss d both X ray and cath te sa ti n re c l d n pulmonary hypertens on whatever It seemed that ope t on was ha dly justifi ble H w *e er m re e perienced plorit n of her tory* l sted the fact that over the p ious 12 month l e l d t e o ghed up small amo nts of blood (sh had d m sed these episodes f om her m nd s of no ac ount) a d the att ck of infl nza eme g d on nalys s as lmo t certainly a fir t bre kdown to co ge ti e *card ac fa lure from wh ch she did not* ecov r for about four month At ope t on a sur p ngly tight tenosi wa found

6—Oft n th doctor cannot follow the sci nti t s d al because f the ety ze of th prol lem Fo e ample e ery ll g in the country can p od ce one or two old *g ff s with ch on c bron hitis emphysema* and suboxyg nat on who are lowly d ter o ting w t r by wi te It would doubtless b go d to know ju t how mu h ubo yg nat on they r endur ng but it s cle rly imposs ble to d arte ial punct es on them all Does it matte alw ys? When does it m tte ? How fa c n th cl n c an t st his *cl nical j dgment* wh n f ed w th such a p tient? Can ny s mpl but still reli bl test be disco d? Can the l n cian t n d n th se techn qu s so h rpen hi purely cl ical j dgm nt th t h can event ally d scard th t chn ques

7—It has al ay be n tru that the fut re of m di n d pend gr atly on the p tis ng phy ic n a m l t ng and metabol ing contemporary d s coveries in the bas c d sciplines of physiology bio chem try pathology and the rest If I were a benevolent dictator I would d mand the young man who wishes to become a practising phys cian in a te ching hosp tal should have pent a year or two in one of these basic departments—in my view after he ha l arned clinical nous in the wards If he wish to take a special intere t in re piratory disea e he ought moreover to work in the rele ant scient fic d sc pline including the carrying out of pecial d techn que nd the exercisin of his mind on the problems n ol ed Later when he s a phys an h will eventually become too busy to do th m h m self but his laboratory work will always rema n a a background and he will be at home in the field He will b abl to u e it s a basis for self criti ism to check the accuracy of h cl l observation He w ll almo t c rtainly come to know better than the scienti t how appl cable laborato y tests are to his clinical ta k ndeed it is he and he o ly who can int grate the clinical and labor to y d sc pl es and be l le to answer the practical quest on which I have ind ted earlier

I h d ntended earl e but forgot to re ter a protest ag in t th respiratory physiol st s use of the term fibro s e en when h c lls it phy log l fibro is nd cat g that t s not nece sa ily *f b os at all in the lon accepted patholog al en* Young lad on occa o allowed to say No wh n they mean Yes but not physiologi t surely?

Professor D SILVA

One aspect of the m u ement of resp rato y function onc rns the ass s m nt of the mech n cal function of th lung Ther a a number of object o to th determ n tion of th ma imum breath ng ap city such a (a) the n ed for f ll co-operat on by th patient whil t performin a d fficult respir tory man u e of wh h he has u u lly had no pre ou per ence (b) the v riations wh ch have been descr b d in the method of perform ng the te t and (c) perh ps the inadvis b l ty on cl n al g ound of king a p tient to und t ke the c ns d able amo nt of e rt on e quired by the test

W have found that by comb n ng measur m nt on both the fast exp atory and the f t inspiratory ital apa ty curves t pos. bl to forecast urately the m mum l r thing capac ty of n rm l ubj cts

Two po nts are n t worthy the fast e pir tory nd insp r t y cur d fferent n h pe and du i g ma mum b eathing th l mit of insp t on i l ttl below the m x mum in p r to y level The f t *pir tory cu e i ery lose to an expon t l cur e* where s th m jo port on of th f st inspr t ry cur e ry close to t ght line The e cur es ar a good fit to the e piratory nd inspir tory portion of tracin of m mum breathing In other w rd a t c ng of maximum b thing can be regard d as *m d up of po tions of f t expiratory and f st* nsp r tory cur Henc by ssum n the l n t of n p at on to be at d fferent l el of full i piratio and know g the d t on of on mplet p ratory cycle it is po ible to plot a family of curves wh h will indicate the relation hip between the piratory at and th t d l r (p es ed as a p entage of the ital cap city) at any assumed le el of nspirat on These ur es show th t the optimal l mit of in p a

tion varies lightly with the rate of breathing From this data the maximum ventilatory capacity (M V C) at any known rate of breathing can be calculated

A comparison between the M V C calculated from these theoretical considerations correlates very highly with the M V C directly measured for a group of normal medical students

Our experiments on abnormal subjects are not yet complete but it seems probable that it will be possible to forecast the M V C by making appropriate measurements on the fast expiratory and inspiratory curve alone

Dr W A BRISCOE

I find myself in agreement with Dr Cooper s very wise remarks and have at times had doubts as to the clinical usefulness of studies of the mechanism of the lung On such occasion one should remember that the acquisition of useless but interesting new knowledge is its own justification Physicians were applying tourniquets for hæmorrhage before Harvey s discovery of the circulation and his discovery might thus have been regarded useless by the physician of his time

I find that I did not explain sufficiently clearly why blood taken from a wedged catheter is not a sample of blood in the pulmonary vein As soon as you wedge the catheter the blood flow through a group of alveoli is stopped and the continuation of ventilation results in these alveoli containing gas which approaches inspired air in composition When pulmonary venous blood is withdrawn into the catheter it must lose carbon dioxide and take up some oxygen as the result of its exposure to inspired air in these alveoli There is evidence of the low CO_2 values of such samples in the Scandinavian literature If this is not realised wedged catheter samples may be interpreted as representative of pulmonary venous blood

We have heard a lot about diffusion I should now like to say a few words about uneven ventilation perfusion ratios and the very large contribution they make to the *alveolo arterial oxygen gradient of both* normal and emphysematous subjects at rest breathing air

Eighteen mixing studies were done on six normal subjects in Dr Cournand s department and interpreted by new techniques The alveolo arterial oxygen gradient expected from these mixing studies if the lungs were evenly perfused with blood is 10 mm Hg with a standard deviation of 3 mm This component due to uneven ventilation perfusion ratios is only part of the total gradient about mm Hg must *be added for the shunt of blood past the alveoli and* 1 mm Hg or less for the diffusion gradient The total of the three components is thus about 13 mm Hg However the observed total gradient in normal subjects is only about 10 mm with a standard deviation of about 5 mm It appears that our estimate of the component due to uneven *ventilation perfusion* ratios may be slightly too great It was calculated on the assumption that the lungs are evenly perfused with blood There are only two possible ways in which this component could be smaller either our data are wrong or else there is under perfusion of the less well ventilated alveoli in the normal lung In either case the component due to uneven ventilation perfusion ratios is by far the biggest component in the alveolo-arterial oxygen gradient of the normal resting subject breathing air

In studies on emphysematous subjects in Dr Cournand s department the same general conclusions hold Uneven ventilation perfusion ratios account for a very large part of the total alveolo-arterial oxygen gradient so much so that it may be necessary to invoke under perfusion *of poorly ventilated alveoli to* explain the data

Dr A BRIAN TAYLOR

During the last five years my colleague Dr Armitage working in Professor Melville Arnott s Department and I have used a non spirometric technique for differential study of the two lungs Apart from the general information obtained it has been of particular use before operations such as pneumonectomy to assess the competence of the remaining lung to support adequate respiration and also in cases of lung cyst and so on to indicate the need for surgical treatment to increase the *function of the affected side* It has been a simple procedure At the end of routine bronchoscopy and local anaesthesia samples of expired air are withdrawn simultaneously by thin tubes from each main bronchus and from two levels in the *trachea These are analysed for oxygen and carbon dioxide content and the respiratory quotient obtained* Analysis of the relationship of the respiratory quotient of each lung to that of the tracheal samples indicates the relative contribution each lung is making to total respiration

A number of cases have now been investigated in this way Clinical estimation has supported the finding and post-operative results have conformed with expectation One case of total bronchiectasis in one lung was found to have 19 % of the total respiration coming from the affected side and resection seemed too hazardous This was confirmed as afterwards sting on operation the patient s post operative course was stormy and subsequent small respiratory infection led to fatal ano

Dr HUGH JONES

Dr Hugh Jones emphasised the value of using the dyspnoea index (ratio of the ventilation required at a *known rate of exercise to the maximum ventilation*) as a screening test for lung function studies As Dr Fletcher pointed out if the standardised ventilation (S V) were used as the measure of ventilatory cost of work then it did not matter whether steady state was achieved nor within limits how long the subject was able to exercise provided the *work was* done at a rate for which the normal standardised ventilation was known With the step-test described (1) and Dr Wright vane anemometer the apparatus was now very simple and with the same equipment the maximum voluntary ventilation (M V V) could be done as the measure of maximum ventilation The cheap disposable polythene bags readily available commercially would probably easily overcome acceptance and the problem of sterilisation Dr Hugh Jones noted and the problem of Dr Donald that the step test was not *performance test nor* that the dyspnoea index derived from it related to the dyspnoea for any other part of everyday task for which a specific test would be needed The individual values of the S V and M V V measured as Dr Fletcher described were each needed

as p l min r s to t sts of lun function one re on for lting the one to the other was in assessing for e ampl chan in dy n xa and th mechan m of th t change a the result of lur or h art surgery In this respect Dr Hugh Jones agree l ith Dr Coope r marks bout th alue of clin cal judgment but f lt that if a ign or symptom could be me ured then me rement was better than judgment He had great ympathy with those who felt that more nd more l function tests were being produced but sa d that t wa no ev d nt th t cert in group of t sts were useful for rout ne assessment nd he showed sl des of the pro f rmas for those to be u ed at the London Post r duate M d c l School H mme m th Ho pital

On d fficulty with lung funct on t ts was th t th r nges of norm l alues e e depend nt on the parti cular patient s a e sex body position t the t me of th test and so on Apa t f om the nple dy pnoe nde the lun volume were often d n in a clos d ci cuit apparatu as routin si me surements Th remaind r of the tests fell nto two g oups The first g p helped w th analysi of a lowered vent latory capac ty and on isted of s mple timed ital capacity d m ximum expiratory flow t sts or the sl ghtly m complex analy is of the work of breath ng u in methods de loped by Me d and Whittenberg r (2) Th second gro p analysed e ercise vent l tion nd clud d blood gas t ns ons indi es of entil tory ineq l ty (3) now much s mplified at Hamm rsmith by u ing th u ique mass spect ometer des gn d by M h Fowl r nd finally ca bon monoxid uptake f r me sur ng gas transf r to th blood

At H mmersmith they w re st rting egional gas sampling w thin the lungs using the mas spectro meter wh h as Dr Brian Taylor h d mentioned from wo k at Birmingham m ght well uper ede broncho- p om try and certa nly g e ld d in gi t nto lung fun t on

Dr H gh Jones fin hed by m k ng two omment o the th etical p t of l ng fu ct on test Ad erse c itic sm of some tests as in cc r te and poorly rep table co ld b mi placed the mpor t nt i d for a t st was its disc mination n mely its repeat b lity elated to the ran e of ch nge t sh w d fr m n mal to g o ly abnormal subjects Thu v t l c pac ty was more repe table but l d s cr min ting tha the m ximum volunt y ntil tion A u ful an l gy was w th the measurement of length if a long d stanc r ther than a short o e w to b m a red th n a le with co rse di ons (analo ou to test r peatabil ty) m ht then be ati f ct ry l a tly t w often sal tory to reflect wh th r tests m as ed what o e tho ght they d d and he descr bed facto analys s a stat stical p ocedu fo find g to what e tent on te t measured the same thing as an ther (3)

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Dr McKERROW

In the me u em nt of vent lato y capacity on frequently fi d that th ma mum breathing cap city t st takes e ther too much time or n ces itate too much co-operation from th subj ct We have found th s to be particularly true in some feld survey work in whi h we have attempted to collect information on the ventilatory capacity of la ge group of subjects In these cases we have used the timed tal capacity (T V C) which as P ofe sor D Silva has sa d has ce tain theoretical d sad ntages and yet we feel it to be suffic ently accu ate for our purpose

It can be seen on the slides that the relationsh p between the M V V or M B C and the timed vital capacity is quite a satisfactory one in the feld ol servat on stud es The correl tion between the two te ts is about 0 8 which su gests that at anyrate they r me suring the same phys ological function although such a correlation is not h gh enou h to nabl one to pred t the actual results of on test from the other Th remaining two sl des illu trate th repe t bility of the te t hen done in the sam group of people on two different days and also when done on d ffe ent oc as ons by two d fferent ol server Ag in t can be seen that the agreem nt in both ase sati factory

Dr PAYNE

I ould lik to mention the us of Profe sor Don ld s Resp r tor in the c e of an elderly wom n who d eloped re pi tory fa lure following bil t ral adren lectomy As resp r tory failu was ncomplete t w felt that some form of patient trigg r d mech n sm would be most suit ble to ssi t her resp tion She therefore onnect d to the Pneum t on and adequate ntilat on m nt ined by th me n for a pe od of th rty hours

In th ca e th Pn um tron ertainly pro d its worth but the are I think three mpro ements which ould u fully b m de —

1—A qu eter me h n m would be boon to both pat nts and staff I und rst nd f m Profe sor Donald th t this n fact s being provid d

2—To prolon ed u some type of humid fer ntial

3—An ind c tion of the olume of gas be ng l l vered per bre th would b valu ble

Dr A B KINNIER WILSON

Pat ents with re p l omyelit oft n h e very unst bl cardio scular y t ms R sons fo a sudd n fall n blood pressure m ght incl de —

1—P t al destru tion of th somotor c nt l y th d proce Eng t om has hown that th s m y b mpatible w th dry lu gs and no mal blood g es in e ere re p tor ca

—Interferenc w th in p at on by trache l ction Th n p ed r s w thdrawn b ck into the sucke before it eaches th al eoli using a precipito f ll in rt rial oxyg nation

3—Postur l dra na e m noeu res wh ch cause a udden n rea e n the numb r of blocked bronchi a postu cl g d

4—Over p d r mo al of accumulated CO a when the a rw y s sudd nly cl ared and the ventil tion p urc not reduc d Thi m y cause a pre cipito is fall of the previo sly in re sed blo d pres u Th st te s p rt cula ly d fficult to de l with

Dr C M OGILVIE

Dr C M Ogilvie said that the interpretation of values obtained for diffusing capacity and the clinical application of this measurement must depend upon the establishment of a normal range The wide variations in normal values reported in the literature are due in part to differences of technique but it is apparent that there are also real differences among individual normal subjects In Dr Comroe's laboratory in Philadelphia the single breath test gave reproducible values for diffusing capacity (for CO) in the same subject but resting values ranging from 11 to 40 ml /mm /min were obtained in a group of healthy male and female subjects of varied age and size It was found however that there is a definite correlation between diffusing capacity and body size (which is presumably related to the size of the diffusing surface of the lung) and that normal values for women are lower than those for men No significant difference was noted between the values obtained at rest in the young and old age groups Cohn et al (1954) have reported that the maximal diffusing capacity (for oxygen) on exercise progressively decreases with age This maximal value does take into account the whole area of pulmonary capillary bed available for gas exchange Resting values should be sensitive to a diffuse change in capillary permeability but might not reflect a small reduction in total capillary area since the whole of this is not required to function at rest A low maximal diffusing capacity with a normal value at rest in older subjects may therefore indicate a reduction in the number of capillaries available for gas exchange rather than an alteration in their permeability This could be due to the obliteration of larger vessels and does not necessarily point to any degenerative or other primary process in the capillaries themselves

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Dr K W DONALD

Dr K W Donald stated that he could not entirely agree with Dr Bates that anæmia of itself would cause a reduction of the diffusing capacity of the lung In a normal resting person breathing air only 25% of the hæmoglobin arriving in the alveolus was reduced and available for oxygenation whereas in a person exercising violently there would be three times as much reduced hæmoglobin available in the same quantity of blood It would not be suggested that the diffusing capacity was raised because of this Further in cases of anæmia there was usually a considerable increase of blood flow in unit time through the alveolar capillaries The avidity of the blood for gas being transferred certainly affected the quantities crossing the membrane but it was the diffusional properties of the membrane that were being studied which when expressed as a quantity of gas transferred/gas tension gradient ratio would not be affected by such considerations Dr Donald endorsed Dr Bates remarks concerning the value of exercise studies on patients complaining of symptoms during exercise Even if no measurements were obtained one had far more insight into their exercise tolerance Many patients were through no fault of their own very unreliable witnesses about their disability on exercise